COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

April 1959

Air Force Academy, Colorado, Power Plant

Integrating Coal Properties

Oxygen and Carbon Dioxide Corrosion

Testing A Slag-Tap Combustion Chamber

COMBUSTION

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Vol. 30 **No. 10**

April 1959

Feature Articles

Editorials

Departments

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ROBERT D. TAFT
Business Manager

JOSEPH C. McCABE
Editor

E. ROBERT LaCROSSE
Circulation Manager

GLENN R. FRYLING
Associate Editor

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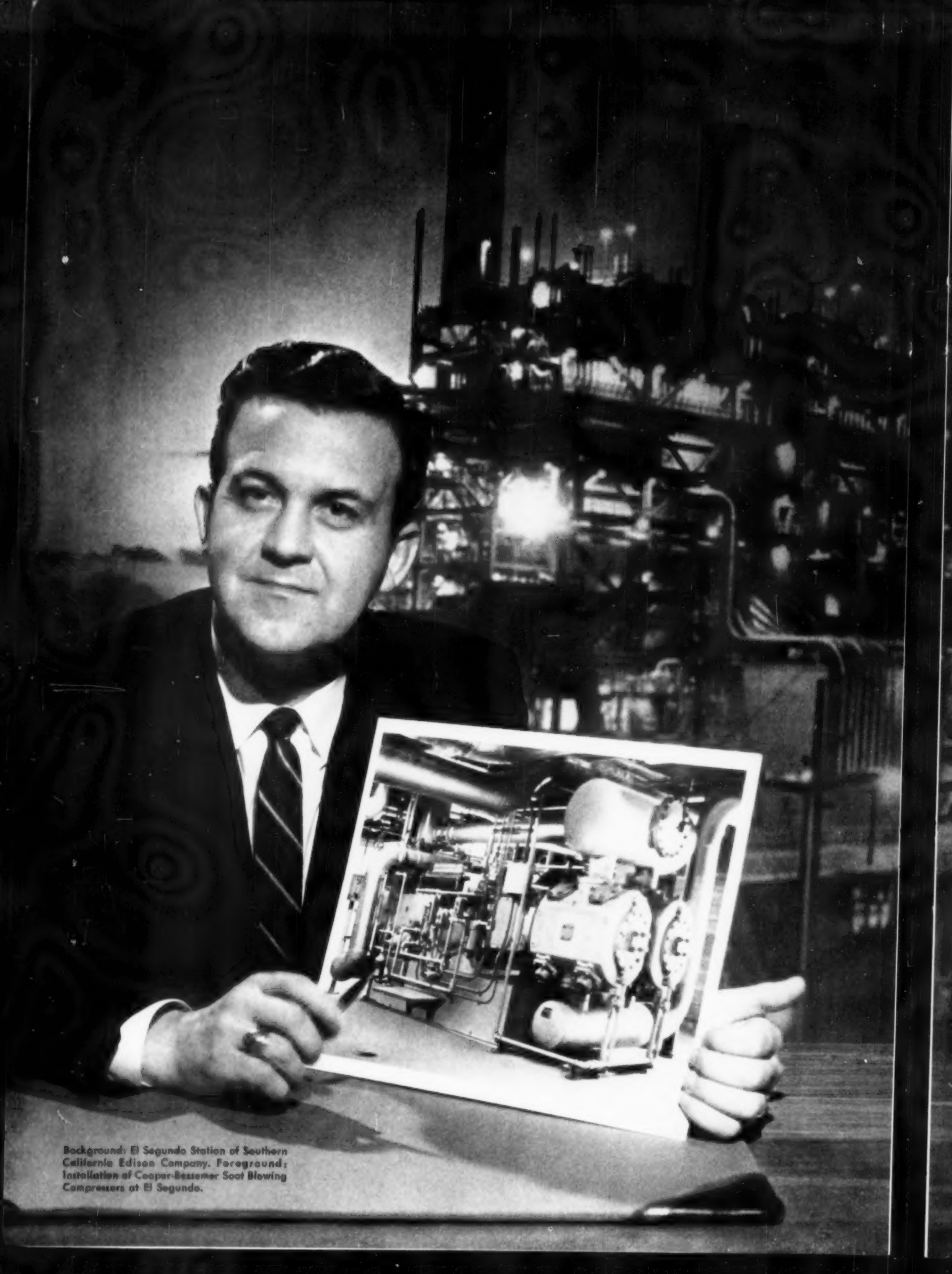

Background: El Segundo Station of Southern California Edison Company. Foreground: Installation of Cooper-Bessemer Soot Blowing Compressors at El Segundo.

Dann Goodson, *Manager Motor-Driven Compressor Sales, The Cooper-Bessemer Corporation, explains...*

How soot blowing with air increases power plant efficiency

POWER PLANTS are switching from steam to compressed air for cleaning of furnaces and tube banks because they can *reduce costs*. The new way, with Cooper-Bessemer compressors, has these important advantages:

1. **Pressure is always adequate to do clean, thorough job.**
2. **Better programming with air... gets better cleaning results for higher boiler efficiency.**
3. **Lower initial cost, lower operating cost, and hence lower cost for blowing medium... less waste.**
4. **No quenching action on hot alloy tubes or pressure vessels.**
5. **Less maintenance of blower equipment due to erosion, corrosion, packing wear.**
6. **Improved housekeeping... no steam or condensate leakage.**
7. **Greater over-all economy of blowing medium on evaluated basis.**
8. **Eliminates condensate makeup required when blowing with steam.**

You can find out more about this by writing for a copy of the article reprint, "Steam or Air: Which costs more for boiler cleaning?" We would be glad to help you in planning your compressor facilities for soot blowing... or other power plant uses. Call the office near you.

BRANCH OFFICES: Grove City • New York • Washington • Gloucester Chicago • Minneapolis • St. Louis • Kansas City • Tulsa • New Orleans Shreveport • Houston • Greggton • Dallas • Odessa • Pampa • Casper Seattle • San Francisco • Los Angeles

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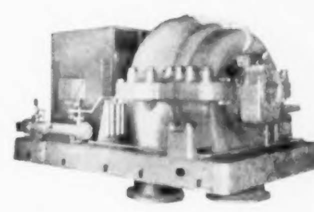
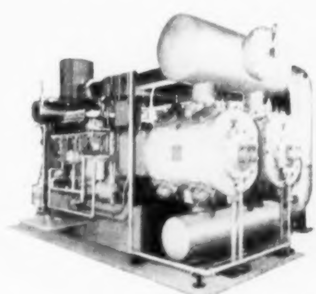


Direct motor-driven multi-stage centrifugal compressor. Sizes of 3000 cfm free air and up.



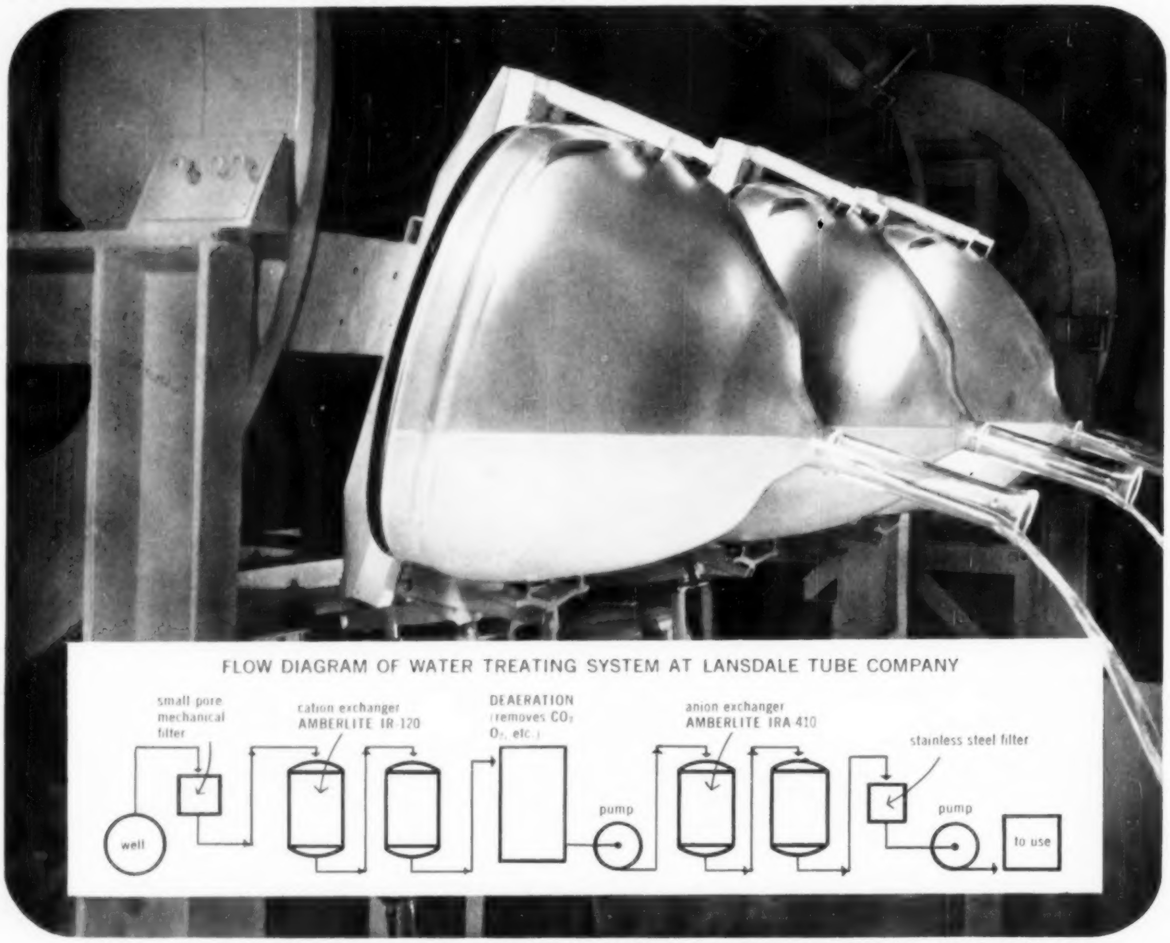
Multi-stage reciprocating compressor. Sizes up to 30,000 cfm free air.

Cooper-Bessemer

GENERAL OFFICES: MOUNT VERNON, OHIO

ENGINES: GAS • DIESEL • GAS DIESEL
COMPRESSORS: RECIPROCATING AND CENTRIFUGAL, ENGINE OR MOTOR DRIVEN

ION EXCHANGE RESINS pave the way for perfect TV pictures



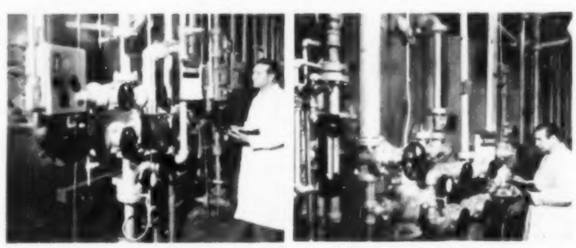
Water pouring from TV picture tubes carried fluorescent powder which has now settled on tube face. It must be free of ions in solution and carbon dioxide to prevent unwanted reactions and insure a smooth, blemish-free screen.

TV needs 100,000 gallons of AMBERLITE-treated water every day, at Philco's Lansdale Tube Co. Division

Plating perfect fluorescent screens on the inside of those big picture tubes calls for water completely free of metallic impurities and carbon dioxide—for washing tubes and preparing phosphor solutions. At Philco's Lansdale Tube Co. Division, the water treating system teams AMBERLITE IR-120 cation exchange resin and AMBERLITE IRA-410 anion exchange resin to provide water free of troublesome ions.

Water from the company's well contains 180 ppm hardness, 240 ppm dissolved solids, 150 ppm alkalinity. After treatment, deionized and filtered water shows over 600,000 ohm electrical resistance at 18°C., twice the required minimum for picture tube use. Water of 20,000,000 ohm resistivity at 18°C. for the manufacture of electronic components is obtained by passing the deionized water through small MONOBED units containing a mixture of AMBERLITE IR-120 and AMBERLITE IRA-400. AMBERLITE-treated water replaced distilled water in all manufacturing processes at Lansdale Tube Co. in 1947.

Can ion exchange help you? Your engineering company, qualified by experience in water conditioning, can tell you how AMBERLITE ion exchange resins may solve your problem. Write today for a copy of "If You Use Water . . ." 24 pages of the latest information on water conditioning.



Cation and anion exchange units in operation at Lansdale Tube Co.

AMBERLITE and MONOBED are trademarks, Reg. U.S. Pat. Off. and in principal foreign countries.

Chemicals for Industry

ROHM & HAAS COMPANY

THE RESINOUS PRODUCTS DIVISION

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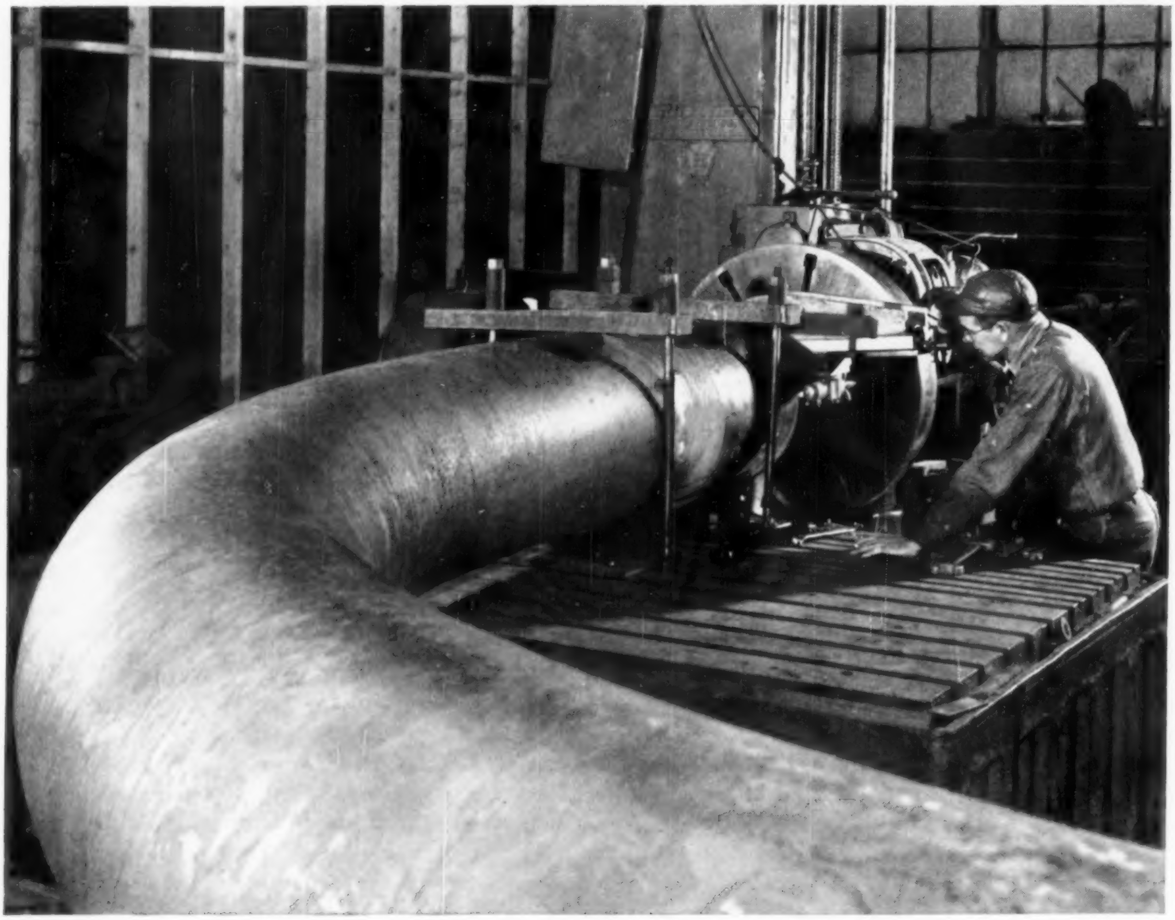


Boring mill cutting bevel on 18" diameter pipe with 3¼" wall in preparation for welding.

QUALITY CONTROL–
key to superior performance

Dravo's Pipe Fabrication shops at Marietta, Ohio, are staffed by highly skilled men who have at their command the very latest in fabricating equipment, including a variety of devices for Quality Control checks. However, at Dravo, Quality Control goes beyond routine checks for compliance with applicable codes. Every step in the fabrication of piping is performed in accordance with procedures developed during Dravo's many years of experience, and is subject to rigid inspection.

Here are some of the Quality Control checks which assure dependable performance in Dravo piping.

1. Radiographic examination of weld. Heavy walled piping may be subjected to several such checks during welding.
2. Heat treatment for stress relieving or normalizing under controlled furnace conditions.
3. Careful preparation of weld area. Dye-penetrant test may be used to assure sound metal at the weld area.
4. Dye-penetrant or magnaflux inspection where indicated.

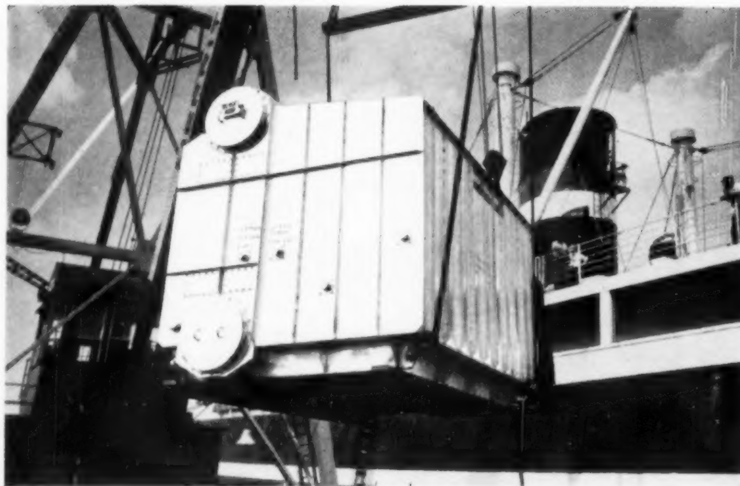
Dravo has the facilities for the fabrication of all kinds of piping. But whether routine or out of the ordinary, every job is held to Dravo standards. A Dravo Piping engineer will be glad to work with you on your next piping job. Write Dravo Corporation, Pittsburgh 22, Pennsylvania.

DRAVO
CORPORATION

DRAVO

Blast furnace blowers • boiler and power plants • bridge sub-structures • cab conditioners • docks and unloaders • dredging • fabricated piping foundations • gantry and floating cranes • gas and oil pumping stations • locks and dams • ore and coal bridges • process equipment • pumphouses and intakes • river sand and gravel • sintering plants • slopes, shafts, tunnels • space heaters • steel grating • towboats, barges, river transportation

A C-E Package Boiler, Type VP, en route to Europe. This boiler type is available with capacities from 4,000 to 90,000 lb of steam per hr, with pressures to 700 psi and temperatures to 750 F in certain sizes. It is designed for oil or gas firing. Several hundred of these units are now in service.



NOW C-E offers LARGER SHOP-ASSEMBLED BOILERS

Three service-proved designs with capacities to 120,000 lb

The economies inherent in shop-assembled boilers can now be yours even if your steam requirements are as high as 120,000 lb per hr. The C-E line, consisting of three basic unit types, has been expanded to include pressures, temperatures and capacities well beyond normal package-type limits.

The standard, natural-circulation, ***C-E Package Boiler—Type VP***—is now available with capacities to 90,000 lb per hr, and with pressures and temperatures to 700 psi and 750 F. Where greater steaming capacity is required, or where higher pressures or temperatures are needed for industrial processing or power generation, the shop-

A shop-assembled Controlled Circulation Boiler, Type PCC, being prepared for shipment. This type unit is available with steam capacities from 80,000 to 120,000 lb per hr, and with pressures and temperatures to 1000 psi and 900 F. For special applications, designs are available to provide higher steam pressures and temperatures. Seven PCC Boilers are now in service.

A shop-assembled C-E High-Temperature Water Boiler, Type HCC, being unloaded at a midwest manufacturing plant. It is one of two 12-million-Btu boilers used for plant heating. Available for capacities from 10 million to 300 million Btu, this unit type is shop-assembled in sizes up to 50 million Btu for oil or gas firing — up to 40 million Btu for coal firing. Currently, more than 50 HCC Boilers are in service or on order.

per hr...pressures to 1000 psi...temperatures to 900 F

assembled ***C-E Controlled Circulation Boiler — Type PCC*** — is available. It is designed for the 80,000-to-120,000-lb capacity range, with pressures to 1000 psi and temperatures to 900 F. For special applications, this unit is also available for considerably higher pressures and temperatures.

The C-E High-Temperature Water Boiler — Type HCC—is an ideal type for large space-heating and certain process uses. It is also available in shop-assembled form for capacities to 50 million Btu per hr. It is designed for pressures to about 500 psi, and can provide water at 450 F or higher.

The new, high-capacity ranges of these shop-assembled units represent the logical evolution of familiar and successful designs that have been proved in service for quality, economy and performance.

Catalogs on any or all of these units available on request.

COMBUSTION ENGINEERING

C-202

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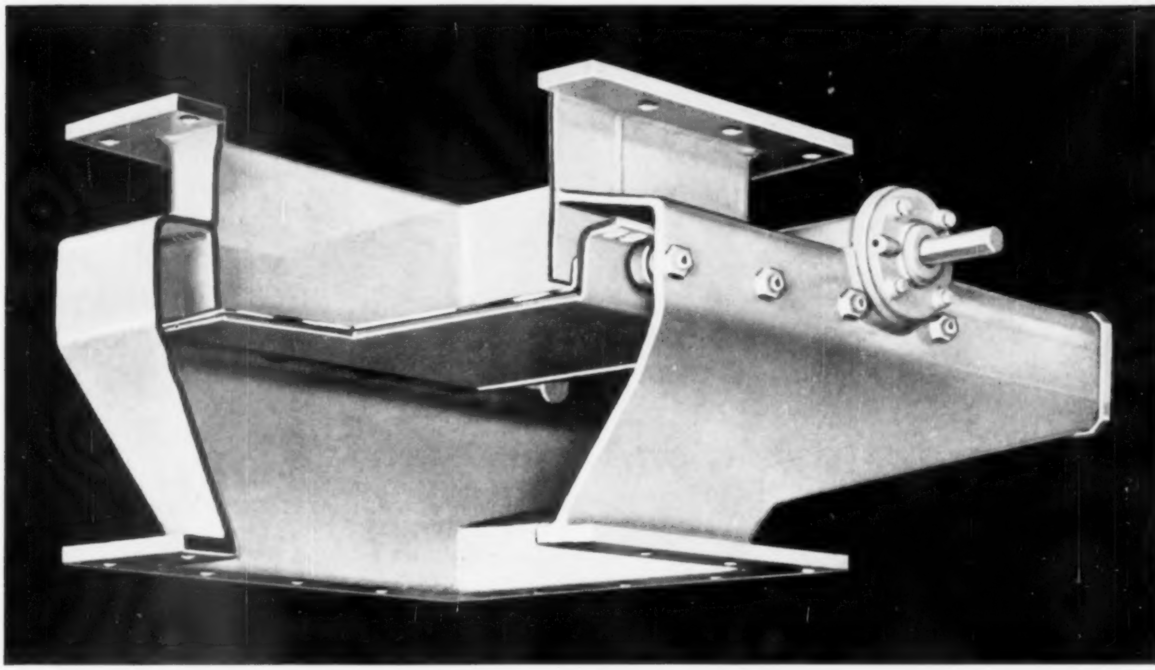
PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE



Here's The Inside Story On The <u>New</u>

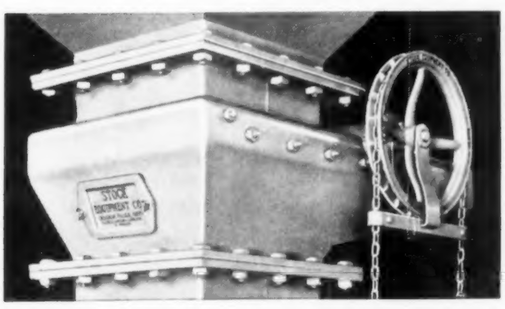
S-E-CO. Coal Valve

Strip the $\frac{3}{8}$" steel skin off our new coal valve and you'll quickly see why *you get more when you buy S-E-Co.*

First, notice the deep U-shaped gate, which completely shields rollers, racks and pinions from coal flow. See how the gate provides lap closure on all four sides assuring positive cut-off. Also, note the stainless steel liner on top side of the gate to combat corrosion.

Carefully formed ladder racks, for their part, are self-cleaning having no root portion in which coal dust can build up and cause jamming. The multi-faced pinions, located above the racks, are also of self-cleaning design. Consequently, the gate moves smoothly with little effort, even after long periods of not being operated.

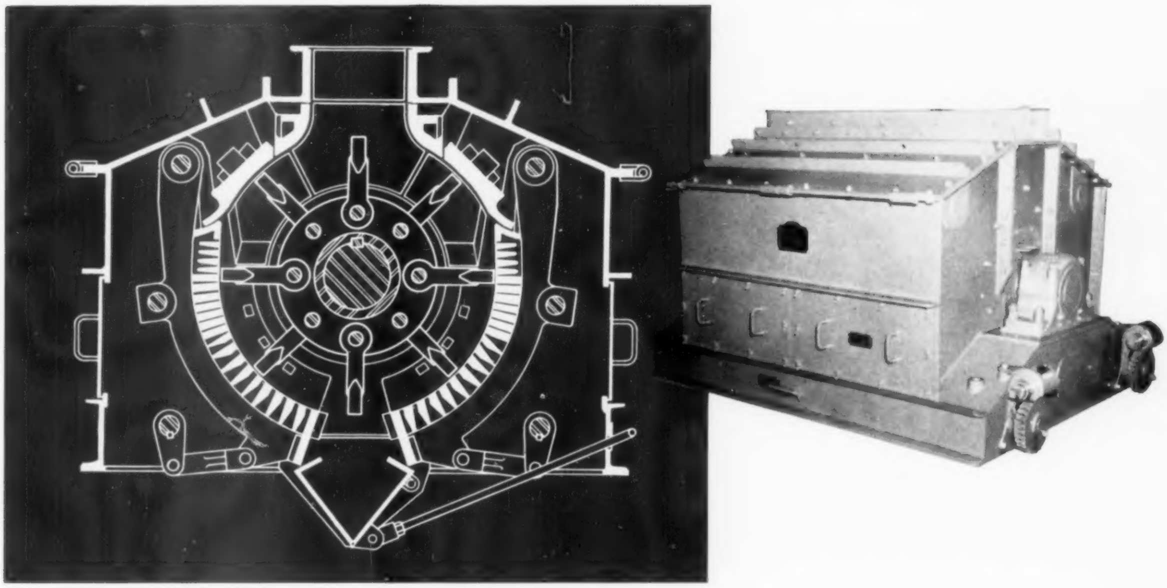
Notice the clean interior design. Slopes have been kept at a maximum with shoulders and projections eliminated. Even the poke hole covers fit flush with the inside of the valve body so that nothing interferes with flow of coal through the valve.



For a complete list of all the outstanding features of the new S-E-Co. Coal Valve together with installation photographs and dimensions, write for Bulletin No. 97.

STOCK Equipment Company

745-C, HANNA BLDG., CLEVELAND 15, OHIO



SPECIALIST

THE MORAL is obvious. It applies not only to the rendition of music but to the prefabrication and erection of critical piping, which most engineers of power and process plants insist on delegating directly to specialists. For your economy, satisfaction and safety . . . ask us in.

W. K. MITCHELL & CO., INC.

Philadelphia 46, Pa.

WESTPORT JOINT
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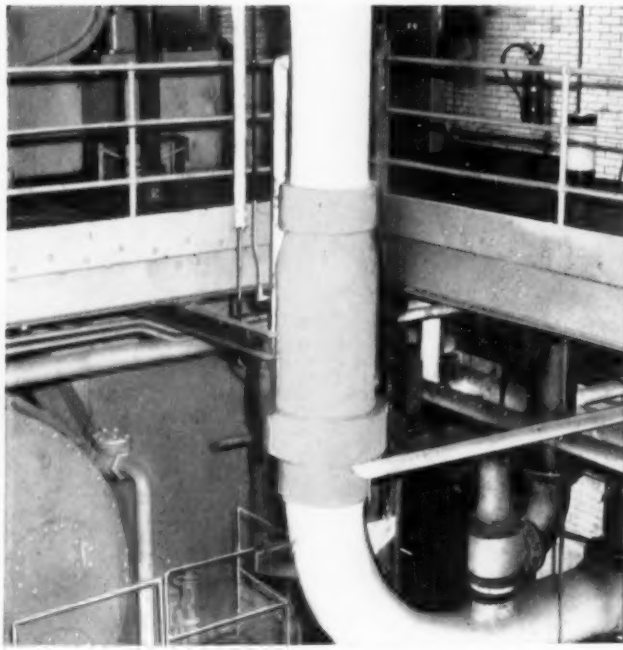
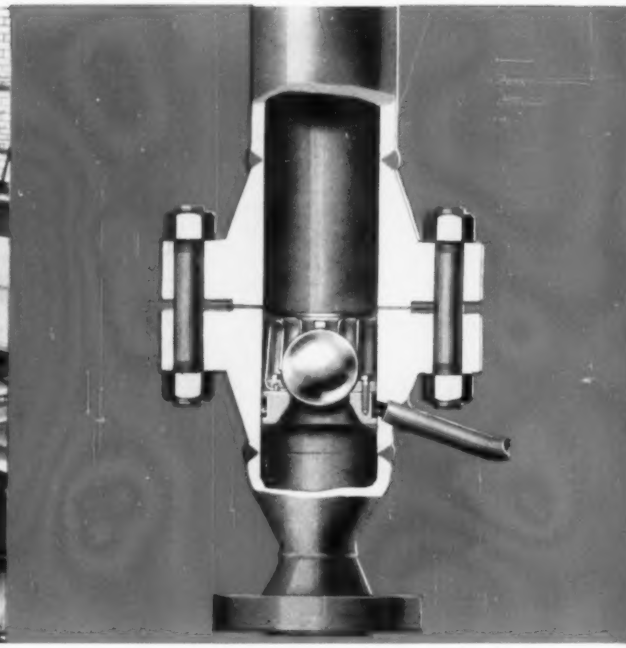
MITCHELL **PIPING**
SINCE 1899

PIPING FABRICATORS AND CONTRACTORS





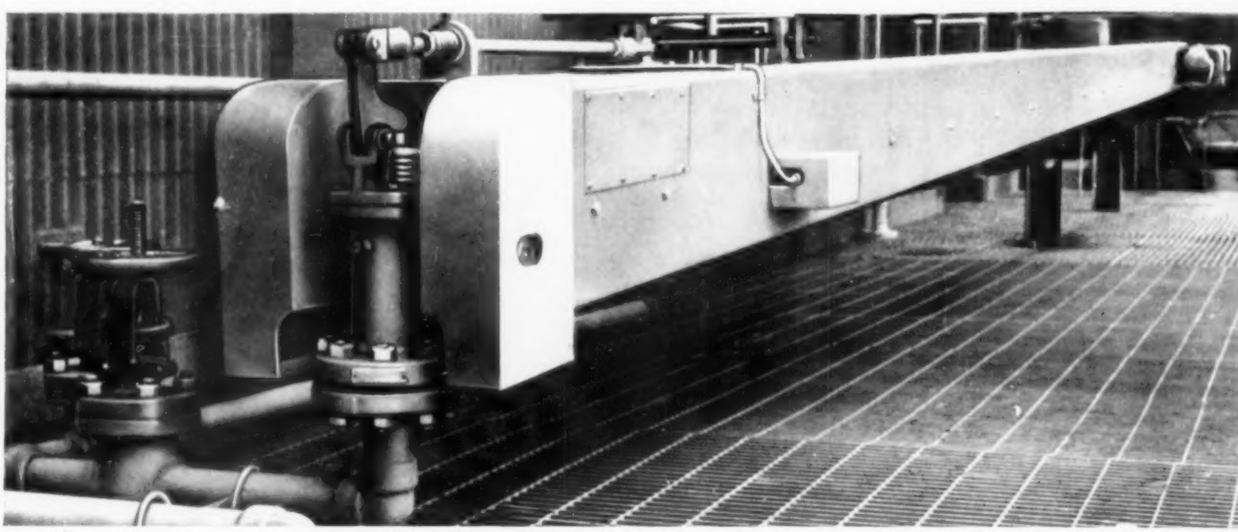
New Variable-Orifice Desuperheater holds reduced steam temperatures constant only 20 feet downstream from desuperheater outlet—regardless of changes in initial temperatures or rate of flow. No long runs of piping or spray nozzles are required. Other types are available, each engineered to particular operating requirements for steam service conditions through 2500 psig and 1100 degrees F. Write for Bulletin 1037.

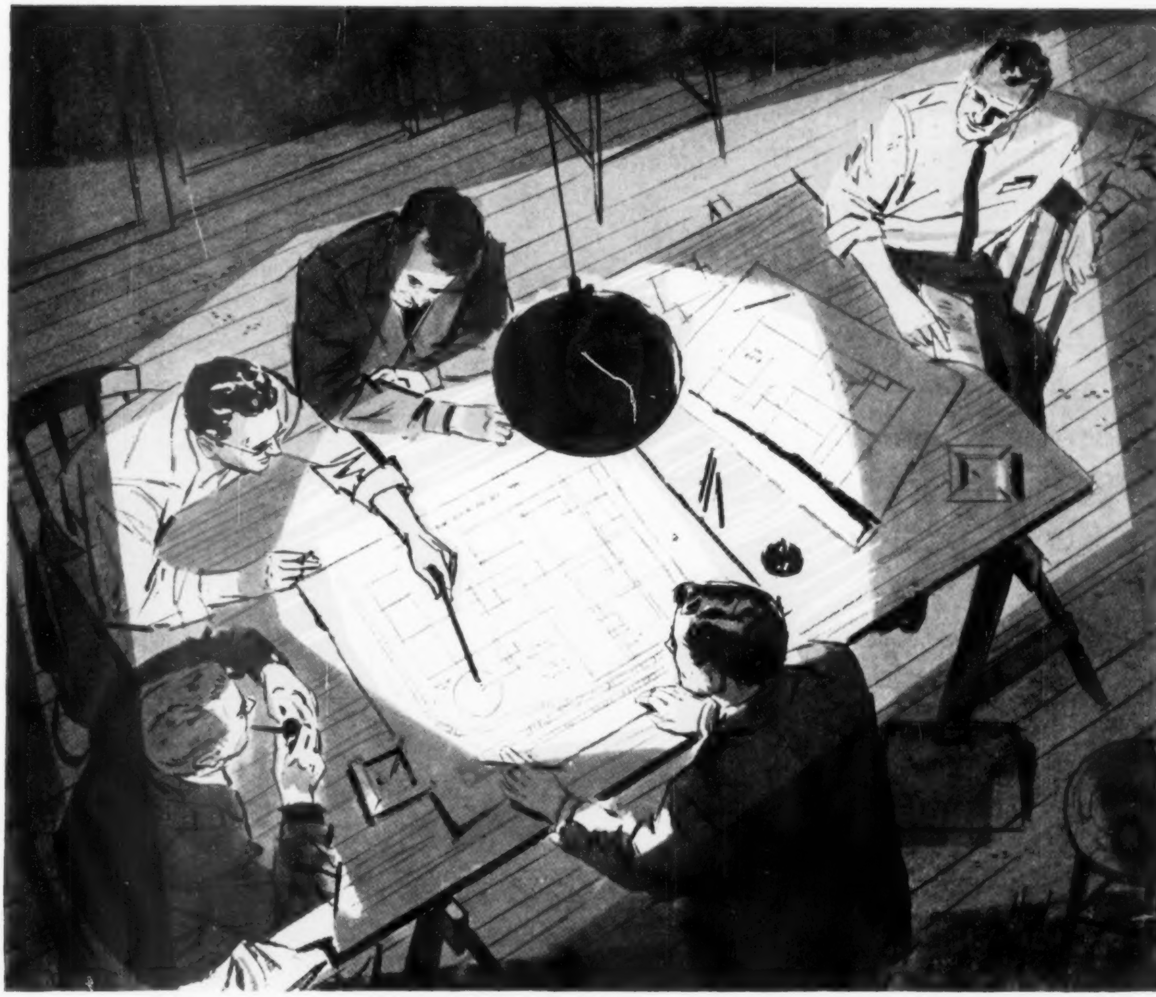
Copes-Vulcan equipment

With the country's electric power demand doubling every decade, power plants must operate with higher and higher efficiency. Boiler and boiler controls must be more closely integrated than ever before.

To meet these needs, Copes-Vulcan produces a complete line of control systems for superheat and reheat temperatures, feedwater, combustion, pressure reducing and desuperheating operations. Available in separate units or integrated into a single package, these control systems are custom-engineered to meet individual specifications, and are backed by more than 50 years design experience in the field.

Automated soot blowing. Vulcan Selective-Sequence Control Panel (at right) permits varying the operating sequence of electrically-driven soot blowers. Also available: Automatic-Sequential systems. Write for Bulletin 1029. The 35 foot Vulcan T-30 Soot Blower (below) has a dual-motor drive for thorough cleaning of all surfaces. Part of a complete line of soot blowers and wall deslaggers. Write for Bulletins 1030, 1034.





We can give you valuable help

In designing, installing or converting water softening equipment

There's no charge for the services of one of Morton's Consulting Engineers at any stage of your work with water softening systems. Many architects and engineers have already found that calling in a Morton man can save time and work and will result in water softening installations that provide maximum efficiency and the greatest economy of operation.

The Morton Consulting Engineers have experience with all types of water softening systems for all types of uses. The assistance they offer is well worth an inquiry. If you think a Morton Consulting Engineer could be of assistance to you, just send in the coupon today.

I would like to know how a Morton Consulting Engineer could help me

I understand there is no charge for this service.

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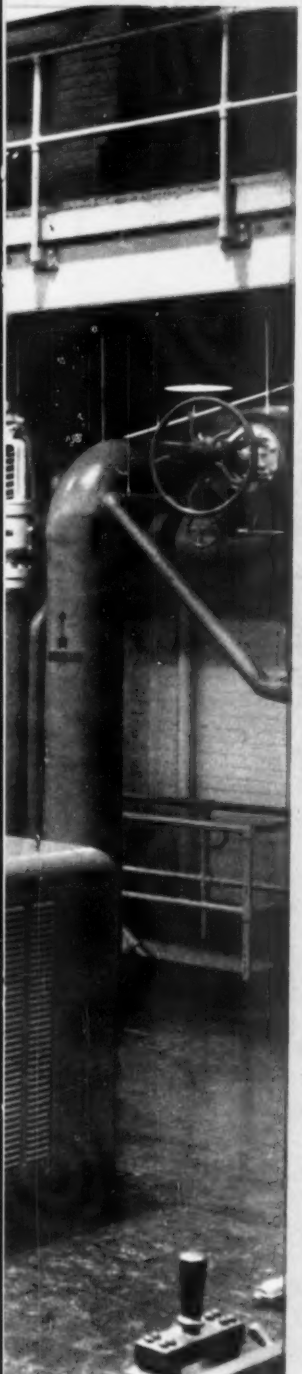


Parke, Davis & Co. uses DE LAVAL Steam Turbines for process and power generation

Proved economy, dependable service

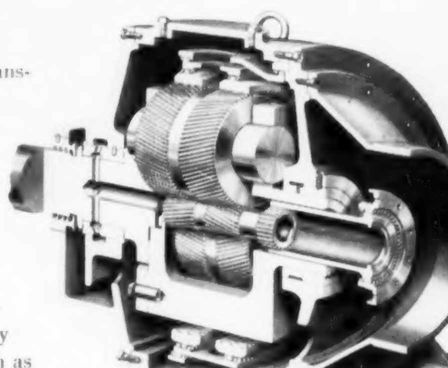
In many process industries, an important by-product is economical electric power. If appreciable quantities of process steam are used, power generation can be achieved at comparatively low cost.

De Laval, pioneer in high speed rotating machinery, has continued to maintain engineering and manufacturing leadership. If you have process application where low-cost power generation can be utilized, call on De Laval.

De Laval-Stoeckicht Planetary Gears

In many applications where high speed and high horsepower are transmitted, the De Laval-Stoeckicht planetary gear can be used to great advantage. It is also used as a speed increaser or decreaser in many industrial installations.

Among its outstanding characteristics are light weight, in-line construction and space saving. It may be used for all kinds of drives such as gas turbines, steam turbines, diesel engines, etc.



Write for Bulletin 2400

DE LAVAL *Steam Turbine Company*

886 NOTTINGHAM WAY, TRENTON 2, N. J.

Hagan Dust Collector gets approximately 20 years use in 14 months

NO MAINTENANCE NEEDED

Two 18-tube Hagan Aerostatic Dust Collectors have passed an unusual endurance test at the Rivesville, West Virginia, station of the Monongahela Power Company. Backing up primary collectors, which expel cleaned gas and pass on the fly ash concentrated into approximately 5% of the total gas volume, the Hagan units are handling a dust loading of approximately 40 grains/cubic foot. *This is about twenty times the usual fly ash loading from a wet bottom boiler.* More than 10 tons are collected daily by each unit, which means that a total of more than 2,500 tons of fly ash are collected each year.

The collectors were inspected at the end of fourteen months. Wear was so slight that *no maintenance was needed!* Plant personnel are pleased, since previously used cyclones needed extensive maintenance approximately every year.

Performance such as this is expected of the Hagan Aerostatic Dust Collector. The inlet vanes are designed to act as a venturi, accelerating the incoming air stream on a six-to-one basis. Heavier dust particles with more inertia are accelerated the least, and the lighter, less abrasive particles the most. This is the exclusive Hagan principle of *Selective Particle Acceleration*, the reason for this unit's resistance to tube erosion. The Aerostatic is low in first cost, low in maintenance cost and extremely efficient. Write or phone for details on this money saving, high efficiency dust collector. Ask for Bulletin MSP-124-A.

HAGAN CHEMICALS & CONTROLS, INC.

DIVISIONS: CALGON COMPANY, HALL LABORATORIES

HAGAN BUILDING, PITTSBURGH 30, PA.
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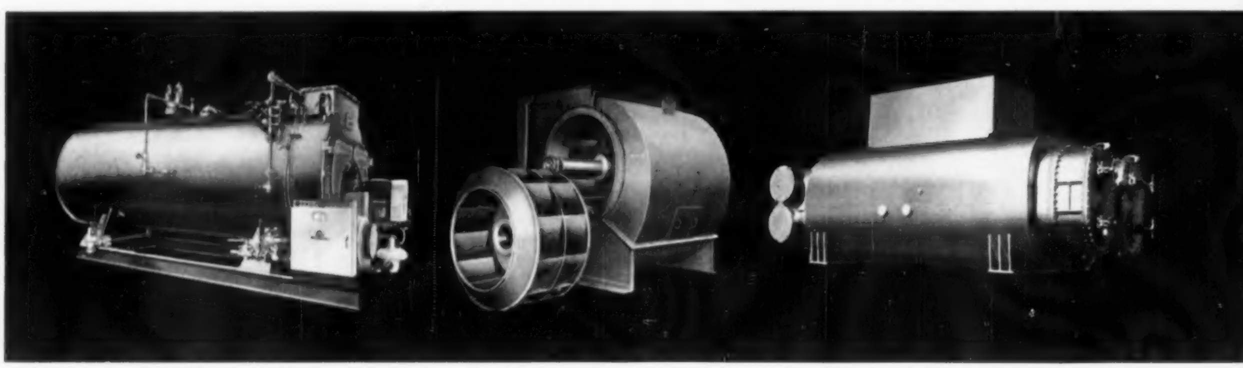
To serve you better we created a new division

Now you can benefit from the combined engineering backgrounds and product lines of three American-Standard* divisions—American Blower, Ross Heat Exchanger, and Kewanee Boiler—consolidated into *one* organization!

Here is *one-source* responsibility for quality and performance in equipment that is designed, engineered, and manufactured to work together. You draw from a product line unsurpassed in the industry . . . one that encompasses air conditioning, heating, ventilating, heat transfer, dust collection, and fluid drives.

There are engineer-staffed offices in all principal cities to work with architects, consulting engineers, and contractors with equipment selection and on-the-job problems. We welcome the opportunity to serve you. American-Standard Industrial Division, Detroit 32, Michigan. In Canada: American-Standard Products (Canada) Limited, Toronto, Ontario.

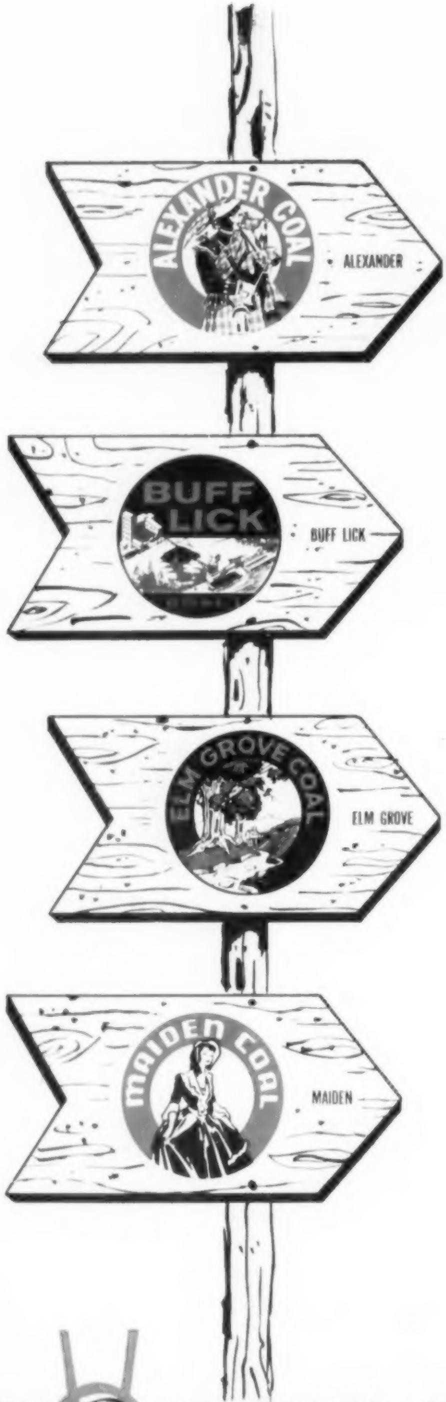


Firebox, scotchtype, and package boilers for heat, steam, and industrial power.

Mechnical draft fans for induced and forced draft duty in power plants.

Balanced-flow surface condensers for condensing turbo-generator exhaust steam.

ONE CALL FOR ALL!



The direct way to

Lowered Steam Costs!

One of these Valley Camp Quality Coals can be a direct way toward lowering your steam costs. They are prepared to specification in modern plants, available for shipment via rail or river . . . and, our combustion engineering service will be glad to "show you how".

© The Valley Camp Coal Company

THE VALLEY CAMP COAL COMPANY

Western Reserve Building • Cleveland 13, Ohio

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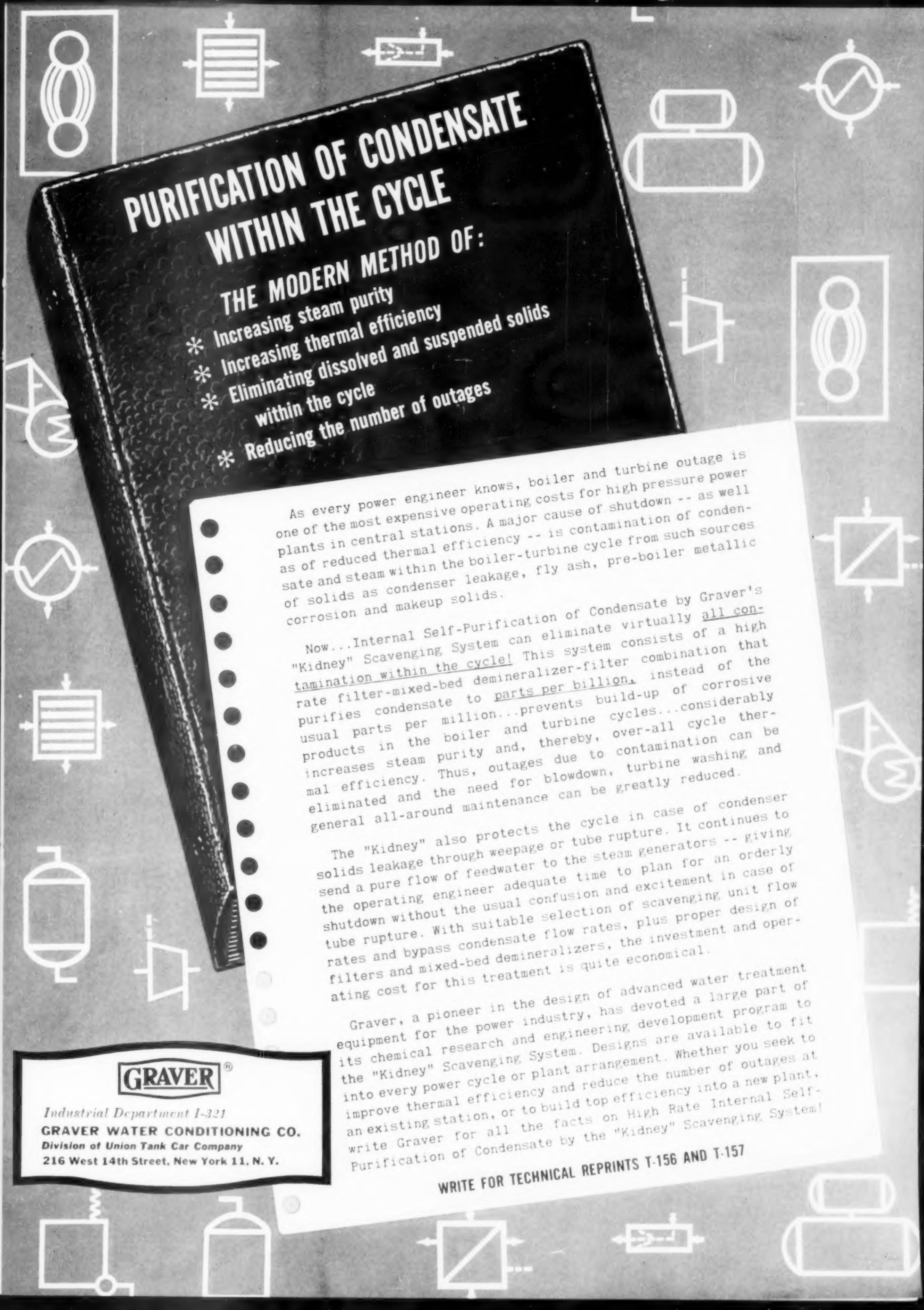
PURIFICATION OF CONDENSATE WITHIN THE CYCLE
THE MODERN METHOD OF:
* Increasing steam purity
* Increasing thermal efficiency
* Eliminating dissolved and suspended solids within the cycle
* Reducing the number of outages
As every power engineer knows, boiler and turbine outage is one of the most expensive operating costs for high pressure power plants in central stations. A major cause of shutdown -- as well as of reduced thermal efficiency -- is contamination of condensate and steam within the boiler-turbine cycle from such sources of solids as condenser leakage, fly ash, pre-boiler metallic corrosion and makeup solids.
Now...Internal Self-Purification of Condensate by Graver's "Kidney" Scavenging System can eliminate virtually all contamination within the cycle! This system consists of a high rate filter-mixed-bed demineralizer-filter combination that purifies condensate to parts per billion, instead of the usual parts per million...prevents build-up of corrosive products in the boiler and turbine cycles...considerably increases steam purity and, thereby, over-all cycle thermal efficiency. Thus, outages due to contamination can be eliminated and the need for blowdown, turbine washing and general all-around maintenance can be greatly reduced.
The "Kidney" also protects the cycle in case of condenser solids leakage through weepage or tube rupture. It continues to send a pure flow of feedwater to the steam generators -- giving the operating engineer adequate time to plan for an orderly shutdown without the usual confusion and excitement in case of tube rupture. With suitable selection of scavenging unit flow rates and bypass condensate flow rates, plus proper design of filters and mixed-bed demineralizers, the investment and operating cost for this treatment is quite economical.
Graver, a pioneer in the design of advanced water treatment equipment for the power industry, has devoted a large part of its chemical research and engineering development program to the "Kidney" Scavenging System. Designs are available to fit into every power cycle or plant arrangement. Whether you seek to improve thermal efficiency and reduce the number of outages at an existing station, or to build top efficiency into a new plant, write Graver for all the facts on High Rate Internal Self-Purification of Condensate by the "Kidney" Scavenging System!
WRITE FOR TECHNICAL REPRINTS T-156 AND T-157
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Division of Union Tank Car Company
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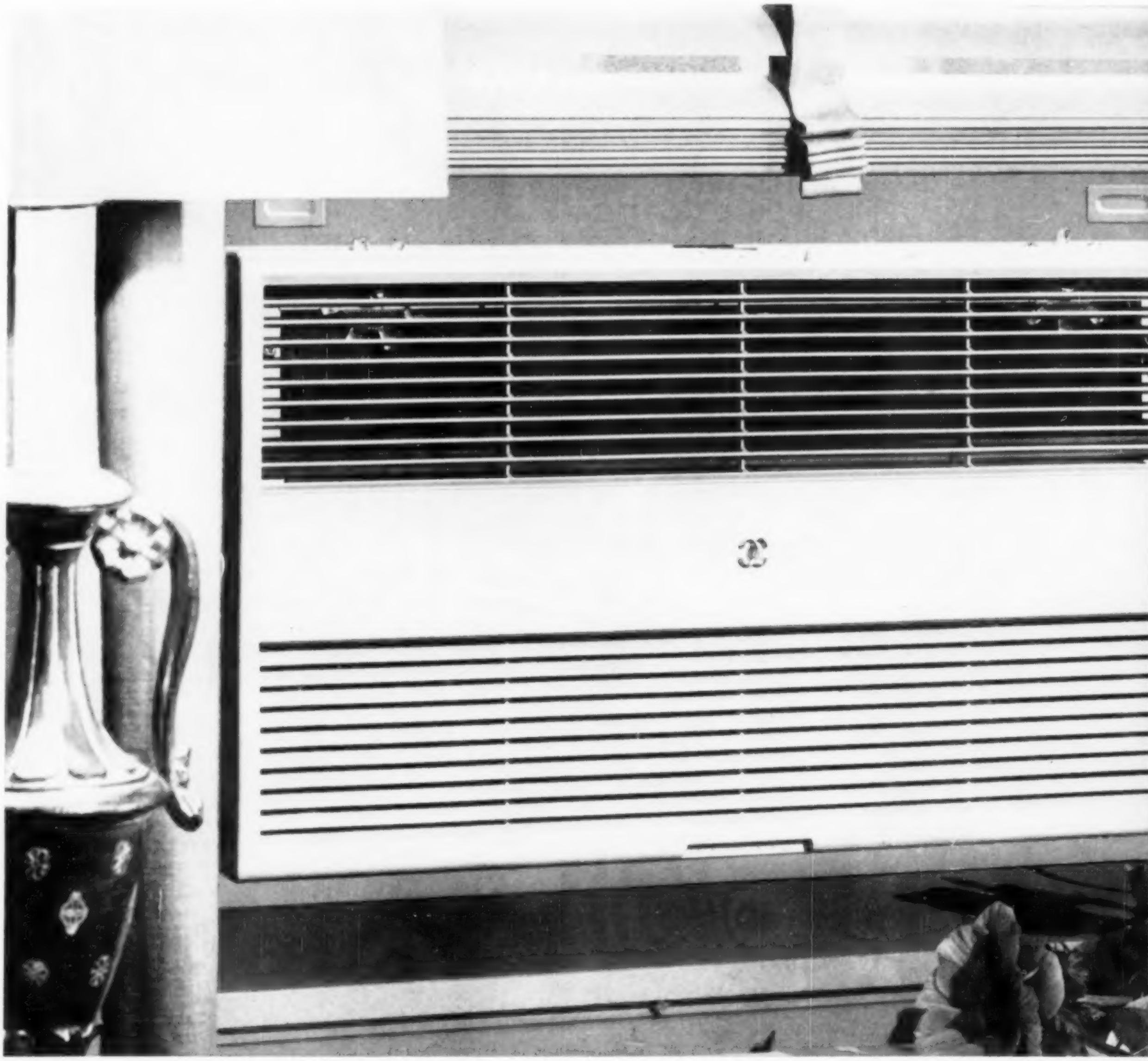

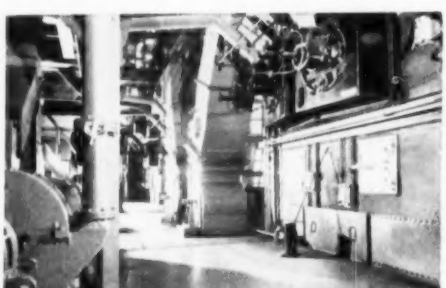

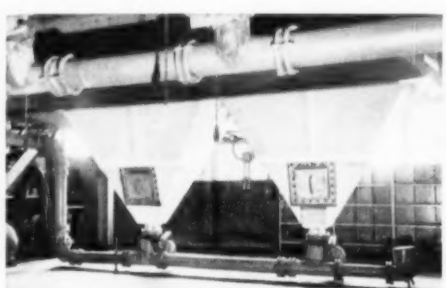

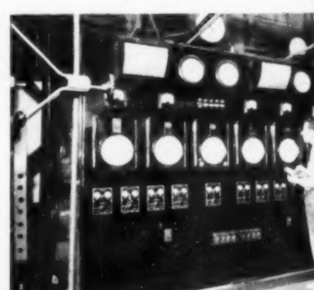

General view of Carrier power plant. Boilers on right are bent tube, two-drum types, by Riley Stoker Corp. burning pulverized coal. Coal moves from bunkers to Riley Pulverizers (at left in photo) and then into furnace.

Mechanical dust collectors by Prat-Daniel Corp. help assure cleanliness of operation. These collectors tie in with United Conveyor ash handling system for movement to ash silo and final disposal.

Pneumatic automatic control panel by Bailey Meter Co. regulates combustion operation of all boilers and auxiliary equipment, maintains continuing steam generation efficiency!

Carrier puts the chill on fuel costs...with coal

Air conditioner manufacturer uses coal for low-cost steam

An unusual team—the heating ability of coal and the cooling facility of air conditioning equipment! Yet Carrier Corporation, Syracuse, N.Y., found this combination profitable when expansion plans required additional capacity in its steam plant. After engineering surveys, Carrier decided to continue burning coal for economy of operation. Today modern power equipment supplies steam *economically* for heating, air conditioning and processing. Original fuel costs plus automatic operation within the power plant hold overall steam costs to a minimum.

Coal is lowest cost fuel

Today, *when the annual cost of fuel often equals the original cost of the boilers,* you should know that bituminous coal is the lowest cost fuel in most industrial areas. And modern coal-burning equipment gives you 15% to 50% *more* steam per dollar, while automatic operation trims labor costs and eliminates smoke problems. What's more, tremendous coal reserves and mechanized mining procedures assure you a constantly plentiful supply of coal at stable prices.

Technical advisory service

To help you with fuel problems, the Bituminous Coal Institute offers a free technical advisory service. We welcome the opportunity to work with you, your consulting engineers and architects. If you are concerned with steam costs, write to address below or send coupon. Ask also for our case history booklet, complete with data sheets. You'll find them informative.

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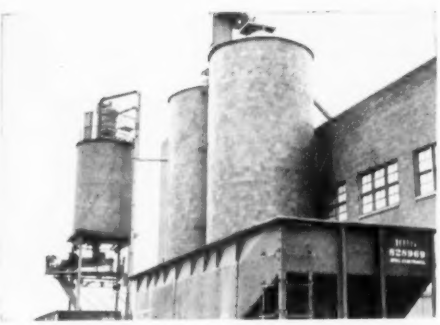

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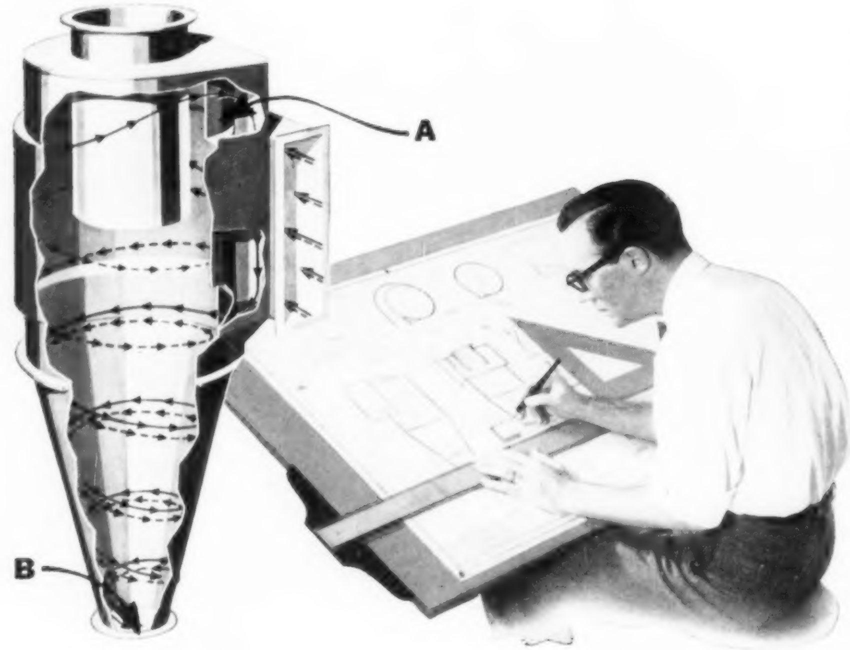

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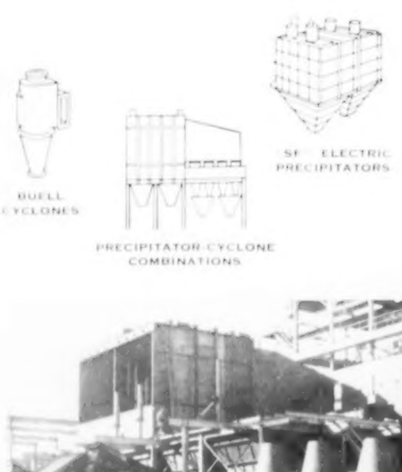

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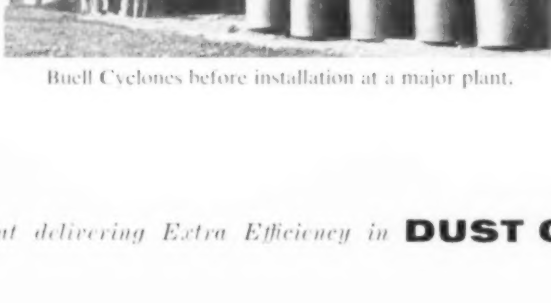

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COMBUSTION

Editorial

The Dwindling Margin

In addition to its usually comprehensive, formal program the recently concluded American Power Conference in Chicago served again as an excellent meeting ground for industrial and central station power men. This meeting ground aspect with its opportunities to talk shop with men of similar interests in outside organizations appeals to all and represents perhaps as strong a reason for Conference attendance as does the formal program. It is from the many little direct conversations and the occasional exchanges overheard—the shop talk, if you will—that individuals gain a feeling of the scope and the depth of the power generating industry and its problems. Now and again a problem first mentioned as an isolated case crops up in other companies and persists and grows to where it spreads throughout the industry. One such problem we heard discussed frequently at the Power Conference was, in a phrase, that of the dwindling margin.

The dwindling margin as we see it is that differential between the directed and the directors. That differential traditionally is measured in terms of financial rewards and job authority. It should be and it must be sufficiently broad in both measures to (1) serve as an incentive to the man coming up and (2) equip him with the authority he needs to discharge his responsibilities properly. From all the comments this traditional concept is collapsing.

In this day and age of general wage contracts, grievance committees and formalized negotiations, the first thought is to believe that if the problem exists it is confined to the area of organized labor. Unfortunately while the comments of the men at Chicago indicated the presence of the problem at this level, the conviction was expressed that this dwindling margin difficulty pervaded into the upper echelons.

We were interested to read, therefore, in our British contemporary, *Engineering*, that the European trade unions have taken steps to establish research staffs to organize and compile data on the many changing facets of an industrial economy. One such facet was revealed in the statement that the differentials for arduous work or special skills are giving place to responsibility payments.

If the need for special rewards for responsibility are to be recognized generally as vital to the efficient operation of an organization, perhaps the pressures adversely affecting the margin will abate and allow ambition to rekindle itself.

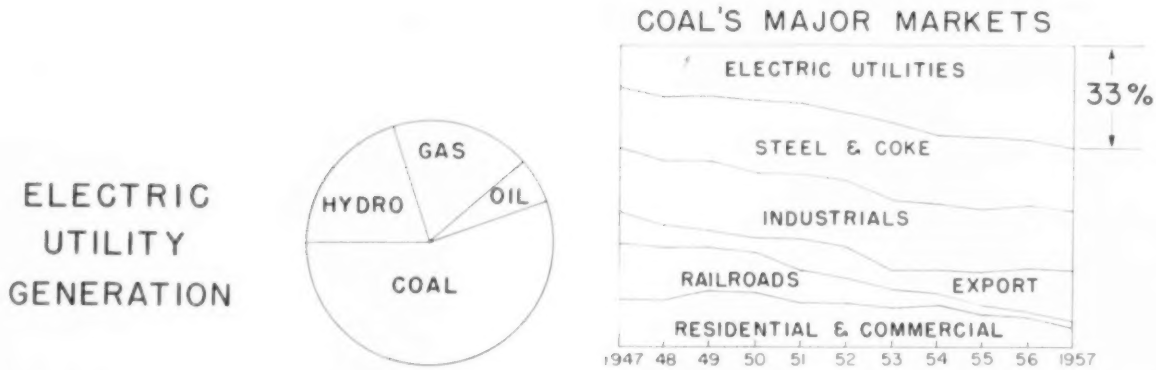

Fig. 1—The importance of coal in the electric generation field is graphically portrayed in the pie chart above. Similarly the major markets for coal are portrayed and the utility company purchases are represented in their proportionate relationships on graph above. Note standing of the utilities.

*Integrating Coal Properties with Boiler Design**

By DOUGLAS G. HUBERT

Combustion Engineering

Of recent years the behavior of coal during the combustion process and the ensuing effect upon boiler availability and deposit build-up has come in for much needed study. This paper tallies and describes the design areas under influence of the various characteristics we now test for in coal purchases.

TO PUT coal in its proper perspective as a source of energy for electric power production, we must first compare it to other energy sources. A report of the Atomic Industrial Forum dated February 1958 records a number of authoritative though widely varying predictions. The most optimistic of these states that by 1968 there will be a total U. S. capacity of about 6000 megawatts of nuclear power, if growth continues at the present rate. Other sources indicate over 200,000 megawatts of total electrical capacity in utility plants by 1968. This is only 3 per cent nuclear. Therefore, 97 per cent of our total power production in 1968 will be from non-nuclear energy.

Fig. 1 shows coal's position in the utility field, and, conversely, the utilities' position in the total coal market in the U. S. The pie chart shows less than one-quarter of the total is hydro and more than one-half of the total is coal. For 1957 the Edison Electric Institute reports that of the total steam-electric generation in the U. S., 68.6 per cent was by coal, 7.9 per cent was by oil and 23.5 per cent was by gas. Thus we can conclude that two-thirds of the steam-electric power in the U. S. is now generated by coal.

The graph in Fig. 1 shows the major markets for coal for 1947 vs. 1957. The greatest percentage increase has been in the electric utility market, where it has more than doubled in the ten years. One-third of the total coal produced goes to the utilities which now represent coal's major market. Utilities used 160 million tons of coal in 1957, and the estimated quantity for 1967 is 275 million tons, and for 1977 it is 525 million tons. It is predicted that 85 per cent of steam-electric power will be generated by coal in 1975.

Although some coal is burned on stokers in central stations, there is a size limitation on stokers and the preponderant number of utility plants burn coal in pulverized form. So we shall concentrate on pulverized coal.

Fig. 2 is a check list showing ten properties of coal and twelve components or auxiliaries of large utility boilers. A black square indicates that a specific coal characteristic has influence on a particular component's design.

A glance at this check list reveals the strong influence of ash percentage, ash composition, and ash fusion temperature. A very interesting observation is that heating value directly affects only two items, pulverizers and burners, and yet Btu content has been the time-honored yardstick for coal purchasing.

It would be one thing if all the characteristics of coal were known for a given installation and could be expected to be maintained for the life of the installation. But this would be wishful thinking. Very often a steam generating unit must be designed for coal which can be expected to vary over a period of time, from year to year, from day to day, or even from hour to hour, and often this variation over the long term has a down-grading trend. It is not uncommon, particularly in the Southeast, to have a yearly summary of coals used in a given plant read as follows: heating value 11,000 to 13,000 Btu's per lb; volatile matter 21 per cent to 35 per cent; sulfur 0.7 per cent to 4 per cent; ash 6 per cent to 20

* Presented at the Annual Meeting of the AIME, San Francisco, Cal., Feb. 15, 1959 under the title "The Integration of Coal Characteristics with the Design of Large Pulverized Coal Steam Generating Units" as Paper No. 59F30.

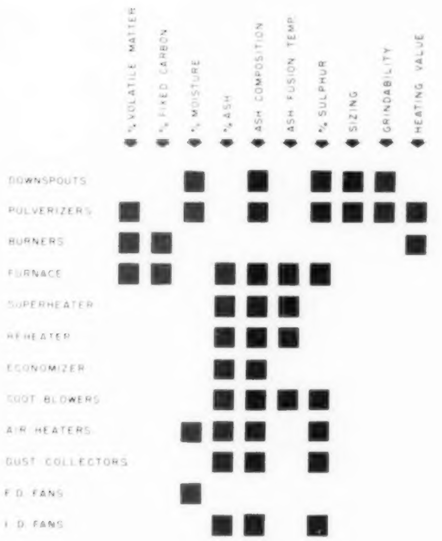

Fig. 2—Check list relating ten properties of coal employed in evaluating the fuel as against their influence on twelve boiler components

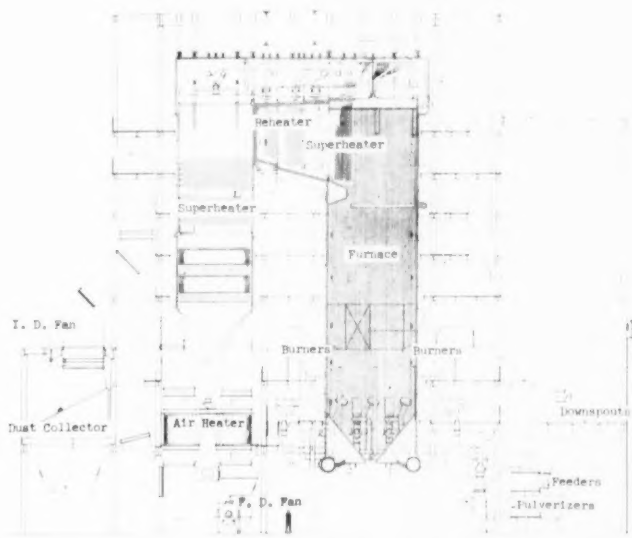

Fig. 3—A typical steam generating unit with these twelve components and auxiliaries of Fig. 2 identified as to their position on the boilers

per cent; moisture 5 per cent to 15 per cent; grindability 40 to 90 Hardgrove; ash fusion 2300 to 2800 deg F; and sizing from run-of-mine to $\frac{1}{8} \times 0$.

We are now ready to consider the influence of the various properties of coal on the design of a typical steam generating unit. Fig. 3 shows such a unit, complete with all its components and auxiliaries. This is a controlled circulation reheat unit for the Danskammer Steam Station of the Central Hudson Gas and Electric Corp. Its design pressure is 2700 psig and it generates 950,000 lbs of steam per hr at 1050 F and 1000 F reheat.

Downspouts and Feeders

Fine wet coal may cause downspout plugging and fine dry coal may cause flooding of the feeders. On the other hand, very coarse coal may cause jamming of the feeders. Sulfur may produce acids which corrode carbon steel surfaces. Also, abrasiveness will intensify the wear on corroded surfaces. Expensive stainless clad steel on downspouts, coal valves and scales, and feeder hoppers, will reduce this corrosion and erosion to some extent.

Pulverizers

The number and size of pulverizers, or mills, for a given boiler depend on the weight of coal to be burned, which is directly dictated by heating value. In addition, the capacity of a mill is affected by the percentage of moisture, the grindability and the required fineness of grind. The largest mills in operation today have a capacity of 30 tons per hour, based on 55 grindability and 70 per cent through 200 mesh. 50 ton per hr mills are being designed. Boilers rated at 200 megawatts and over may have anywhere from five to ten mills per boiler.

Grindability and wear are not necessarily related. Wear is a function of both the hardness and abrasiveness of the materials being ground, whereas the grindability index merely indicates the relative ease with which the coals are broken down to a definite sizing. However, a coal of 100 grindability will generally produce less wear than one with 50 grindability because there are fewer of the harder fractions in the higher grindability coal.

The fineness required for burning is largely a function of volatile matter and the burning qualities of the fuel. The high volatile coals do not require as high a fineness as the low volatile coals. The freer burning coals do not require as high a fineness as do the coking coals. The higher the fineness required, the lower the capacity of the pulverizer. The fineness requirement varies from 65 per cent to 85 per cent through 200 mesh.

Before certain coals can be burned properly, a part of the moisture must be removed. The pulverizer can perform this function effectively, but high surface moisture will limit the capability of the pulverizer in pounds of fuel fed per hour. It is desirable, therefore, to keep the moisture content of the raw coal as low as possible.

Approximately 50 per cent of the sulfur in coal is in pyritic iron form. Much of this is in solid heavy pieces and is thrown out from some pulverizers through a so-called tramp iron spout. This material must be removed periodically by manual means, or through a continuous discharge system.

Sizing of raw coal is not as important with pulverized coal as with stoker fired coal. However it is a factor to some degree. It is customary to specify $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. $\times$ 0 for the large pulverizers.

The pulverizers should not be selected on the basis of the highest possible moisture fuel obtainable in combination with the lowest grindability and the lowest heating value, unless a definite fuel having this combination of characteristics actually exists. This would mean that for the average coal used the pulverizers would be considerably oversized. The pulverizers would be operating at reduced capacity most of the time, and since power requirements per ton of coal pulverized increase as capacity is reduced, plant auxiliary power would be higher. Also, maintenance costs per ton increase with decreased

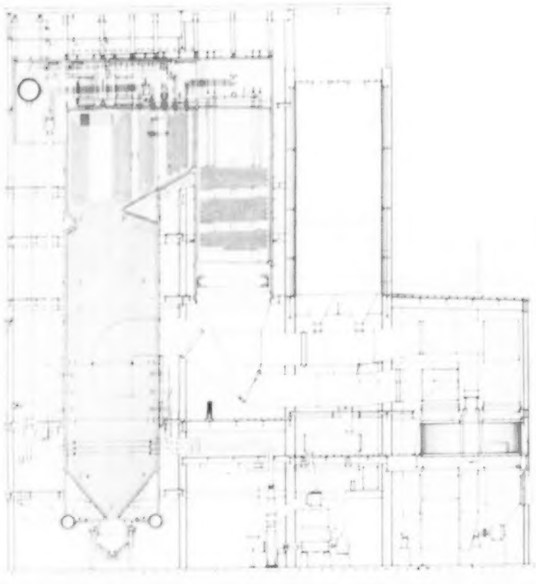

Fig. 4—The twin furnace boiler has been designed to serve large unit outputs, lower quality coals and still give long boiler availability

capacity because wear is more a function of service hours than tonnage. A better job of pulverizer selection and pulverizer operation will result if the coal vendor can assure the plant operator of a continuing supply of the originally specified coal, or of coals having a narrow range of the characteristics mentioned above.

Burners

The chief function of the burner is to mix the air with the coal so that the coal ignites and burns. This may be done almost entirely within the burner itself, with the furnace acting only as an enclosure for heat absorbing surfaces. On the other hand, the furnace may be required to act as the burner, being a mixing chamber as well as a heat exchanger, with the principal mixing of air and coal occurring in the furnace away from the so-called burners or fuel delivery nozzles.

Anthracite coal, with its extremely low volatile matter, requires a long burning time and a long distance for flame travel to burn the fuel completely. Vertical burners may be located in a furnace arch high up in the front or side walls of the furnace. A long U-shaped flame is produced and a portion of the air for combustion is introduced in the lower section of the furnace.

In this country, of course, the predominant fuel is bituminous with its considerable range in volatile matter. One type of fuel burning equipment adaptable to the full range of bituminous and lignites is the tangentially fired furnace where complete mixing of coal and air occur in the furnace proper. The wide variation in ash contents and ash compositions in coals as delivered to a given station produces changes in the slagging and ash accumulating propensities of a furnace. This in turn means a change in the effectiveness of the heat absorbing surfaces and a resultant change in the furnace exit gas temperatures. With tangential firing the burners are designed to tilt upwards and downwards through a total angle of 60 degrees. Changing the position of the burners to suit current furnace heat absorbing conditions makes the proper effective heating surface available.

Furnace

The temperature of the gas leaving the furnace and entering the convection surfaces must be low enough to prevent fouling of these surfaces. This temperature is dictated by the ash fusion temperature of the coal. The furnace walls will be coated to some extent with dry ash or slag, so that they absorb less heat from the burning fuel and hot furnace gas. One measure of the degree to which furnace slagging will occur with a given fuel is heat release rate, in Btu's per square foot per hour. A high quality Eastern bituminous coal will permit a higher heat release, and a smaller furnace, than most Midwestern coals. Since the alkali and iron content of the coal have a direct bearing on slagging tendencies, their reduction by washing, or any other method of cleaning, makes possible a smaller furnace.

Superheater, Reheater, Economizer

The major cost of a modern utility boiler lies in the superheater and reheater. If the ash characteristics demand a low gas temperature leaving the furnace and entering the superheater, there must be a correspondingly large quantity of this expensive surface. Wide tube spacings must be used in the high temperature sections to prevent bridging of slag between tubes. In the low temperature sections and in the economizer, allowable gas velocities will set a minimum on tube spacing, in order to reduce erosion from ash particles. These spacings determine the gas mass flow and in turn the heat transfer coefficients and the heating surface. Thus a low-grade coal will dictate not only a large furnace but a large superheater and reheater.

High metal temperatures in superheaters and reheaters call for alloy tubing, and the attack on alloy tubing at high temperatures by alkalies in the coals is one factor in limiting steam temperatures. Any inherent or added constituent which increases the alkalinity of the coal above 0.4 per cent may result in serious difficulties. If such alkalies can be eliminated from coals in preparation plant treatment or storage procedures, it may help to raise the ceiling for steam temperatures.

With the increase in the size of units and decrease in the quality of coals, furnaces have been getting larger, with furnace exit gas temperatures decreasing. With higher steam pressures and temperatures it has become increasingly more difficult to get sufficient heating surface in convection type superheaters and reheaters. Fig. 4 shows a twin furnace boiler, one of four 200 megawatt units in operation or under construction for Niagara Mohawk Power Corporation's Huntley and Dunkirk stations. The finishing stages of the superheater are at the top of one furnace and the reheater is at the top of the other furnace Platen superheater and reheater surfaces are employed for this 2400 psig job, so that sufficient heat is absorbed by radiation to achieve the required steam temperatures of 1050 F in the superheater and 1000 F in the reheater. These platens on wide spacing, approximately 16 in., absorb heat by both radiation and convection, and yet because of this wide spacing, and because of the tangent tube construction in the direction of gas flow, this surface is not subject to

slag accumulations which cannot easily be removed by soot blowers.

Ash Deposits

A pause is made at this point in the orderly progression of equipment to emphasize and add perspective to the vital problem of ash deposits. The subject is pictured in Fig. 5. At the risk of over-simplification, the nature of the problem, the cause and the cure are briefly presented.

Although much research is being done on coal ash, reliable ash analyses are not usually available to the designer. He does have a clue, however, in the per cent of sulfur in the coal. Generally, high sulfur content means high iron content, as the small graph in Fig. 5 shows. High iron content is a sure sign of trouble, as shown in the temperature diagram in Fig. 5.

The two vertical lines in this diagram show the three characteristic ash temperatures: I.D. (initial deformation), S.T. (softening temperature, better known as ash fusion temperature) and F.T. (fluid temperature). In general, the higher the iron content, the lower these temperatures, and the greater the difference between these temperatures in a reducing atmosphere and in an oxidizing atmosphere. There is also evidence that a low I.D.-S.T. spread is an indication of trouble.

Above the fluid temperature, the ash particles in the furnace, when deposited on a tube surface, are completely fused together and form a hard, homogeneous slag when cooled. At lower temperatures there may be a combination of slagging and sintering of partly deformed particles.

Even below the initial deformation point, sintering of underformed spherical ash particles may occur, due to a sticky coating of condensed alkali vapors. This type of deposit generally appears in the cooler gas zones, among the convection banks of the superheater, and is often very difficult to remove. Further, the slagging bottom unit is partially susceptible to this phenomenon, because, first, the burning zone is at a higher temperature and more of the alkalies are vaporized, and, secondly, there is less fly ash in the gas and therefore a higher percentage of vaporized alkalies.

Apart from restricting the alkali content of coals to be fired, it is apparent that the reducing atmosphere of the burning zone must be restricted to as small a fraction of the furnace volumes as possible, and the ash hurried into an oxidizing atmosphere. This is shown diagramatically at the bottom of Fig. 5 with a list of the factors which constitute the cure for the problem.

These factors are within the control of the operator, providing the ability to control is built into the equipment. One factor is coal fineness from the mill, and, with respect to ash deposits, the per cent left on 50 mesh is more significant than the per cent through 200 mesh. Theoretically, a 50 mesh particle takes 16 times as long to burn as a 200 mesh particle, so that the 50 mesh particles will retain a localized reducing atmosphere well up in the furnace. The 50 mesh particles should be held to 1 or 2 per cent.

Other factors are sufficient excess air, which must be available at the forced draft fan, air temperature, which is the function of the air heater, and coal-air mixing, which requires properly designed and operated burner dampers. Furnace size, soot blowers and tube spacing are considered below.

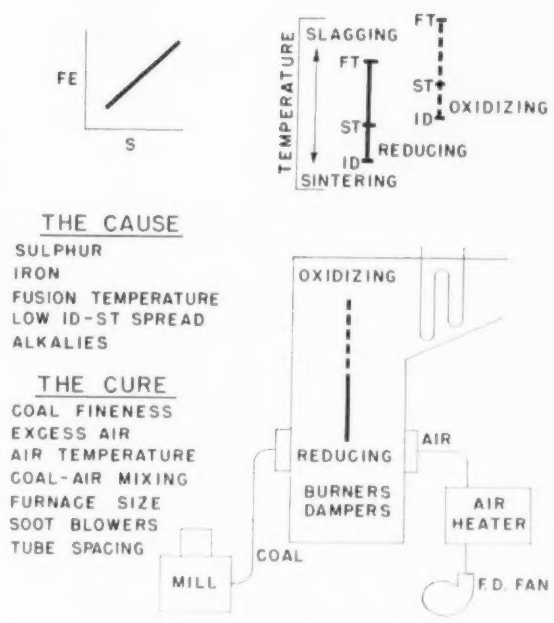

Fig. 5—A grouping of figures in which the causes of ash deposit formation are listed and suggested cures advanced.

Soot Blowers

Soot blowers are a necessity in any pulverized coal boiler. These consist of long retractable blowers in the superheater, reheater and sometimes economizer, and short retractable blowers in the furnace walls for deslagging purposes. The grade of coal dictates the number and location of soot blowers required. Ash percentage and ash fusion temperature are the major determining factors.

Figures 6, 7 and 8 show soot blower locations for three boilers burning widely differing coals. All three are designed for 1800 psig turbine throttle pressure, 1000 F main steam and 1000 F reheat, with boiler efficiency 88.5 to 89 per cent. They are of about the same capacity, from a little less than a million to a million and a quarter pounds of steam per hour.

Fig. 6 shows Plant A, burning an Eastern bituminous coal. Fig. 7 shows Plant B, burning a Southern bituminous coal. Fig. 8 shows Plant C, burning a Midwestern bituminous coal.

Fig. 9 is a bar chart showing per cent sulfur, per cent ash, ash fusion temperature, furnace heat release and number of wall blowers in the furnace and long retractable blowers in the superheater and reheater. Plant C has the lowest heat release and the largest number of soot blowers because this plant burns a very low-grade coal from nearby mines. The specification coal had 1.3 per cent sulfur, but a newly opened seam yields coal with as high as 13 per cent sulfur. Blending will be required, and Fig. 9 shows 7 per cent sulfur. Also this coal is unwashed.

At this point it may be interesting to compare the lateral spacings between superheat and reheater elements and the gas velocities for these three plants. Fig. 10 makes this comparison. In each case, the widest spacing

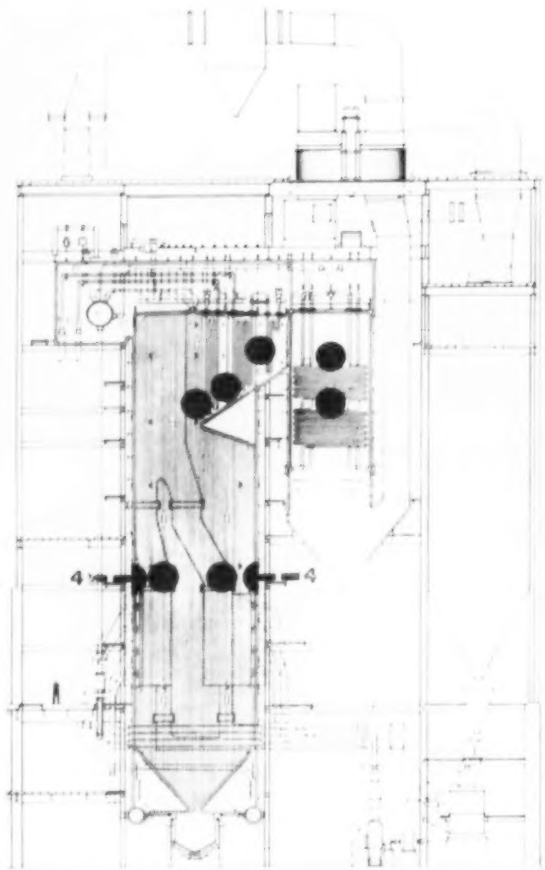

Fig. 6—Soot blower locations for a plant called "A" burning an Eastern bituminous coal

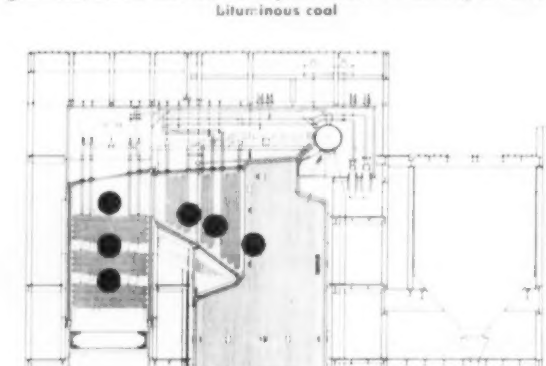

Fig. 7—Soot blower locations for a plant called "B" burning a Southern bituminous coal

is at the point of gas entrance, where slagging may occur, with a decrease in lateral spacing in the direction of gas flow. Close spacings in the cooler zones is dictated primarily by the need for large amounts of surface, due to the progressively decreasing heat head in the counterflow heat transfer system. Draft loss sets an economic minimum spacing, but gas velocity, with the potential hazard of tube erosion from fly ash, also takes a hand in setting this minimum. The curves at the bottom of Fig. 10 show the gas velocities in feet per second, progressively through the unit.

Air Heaters

With the cost of fuel rising, higher boiler efficiency is demanded. Heat recovery equipment includes the economizer and one or more air heaters, with a low exit gas temperature from the air heaters. Utility companies are going as low as 250 F or lower in exit gas temperature. Gas at these temperatures approaches, or falls below, the dew point, and acid corrosion is quite common. With high sulfur coals this makes necessary extensive protection devices to avoid corrosion. Steam or hot water coils and hot air recirculating ducts are in common use. Most air heaters have a removable cold end made of alloy elements designed to resist corrosion to some extent. All of this points to the value of removing sulfur from utility coal.

High ash coals may cause plugging of the heating surfaces in air heaters. Soot blowing and water washing devices are commonly incorporated in air heaters. A soot hopper in the gas duct ahead of the air heater will remove some of the heavier ash particles.

One factor in the selection of the air heater is the variation in the moisture content of the coal. The size of the air heater is chiefly determined by the desired exit gas temperature. Part of the hot air from the air heater is used to dry the coal in the pulverizer, and the temperature of this air is usually more than sufficient to dry the highest moisture coal expected. The temperature inside the mill is limited to prevent fires, so that some air at room temperature, known as tempering air, is mixed with the hot air. This tempering air does not pass through the air heater, and this fact must be considered in designing the air heater.

Forced Draft Fans

Forced draft fans are affected by the tempering air, which is in turn affected by the moisture in the coal, as discussed above. The tempering air generally does not go through the forced draft fan. If coal with a higher moisture content than expected is burned, there may be less tempering air than planned on, with more of the total air for combustion going through the fan, and the fan may be undersized. If the percentage of moisture in the raw coal could be kept down, the tolerances applied in selecting forced draft fans might be reduced.

Induced Draft Fans

Wear and maintenance on induced draft fans are affected by ash percentage and composition. Acid corrosion from the sulfur in the fuel may show up in the induced draft fans when low gas temperatures are involved. The size and static requirement of the induced draft fans is increased by the presence of dust collectors,

with an average of 2½-in. draft loss in mechanical collectors and up to ½-in. draft loss in electrostatic precipitators. Also plugging of convection surfaces by slag and ash may increase draft loss.

Dust Collectors

Atmospheric pollution has received a great deal of attention in recent years, especially when power plants are located in urban or residential areas. On a normal dry bottom furnace installation, about 20 per cent of the ash goes to the ash pit at the bottom of the furnace, and the other 80 per cent is carried out with the gas. With the percentage of ash found in most coals today, it is necessary to install a dust collector to reduce the amount of ash leaving the stack. A well designed mechanical dust collector may take out as much as 85 per cent of the dust in the flue gas, depending on the micron sizing of the dust. Regardless of the method of firing the fuel, or the amount of extraction of the dust by mechanical means, many of the smaller micron sizes remain in the gas. The next step is to add electrostatic precipitators which have an efficiency in the order of 90 per cent. In many cases, mechanical or electrostatic precipitators are placed in series, with a combined efficiency in the order of 98 per cent. All of this, of course, greatly increases the cost of the plant, and reduction in this cost can certainly be made possible by lowering the quantity of the ash in the coal.

Size of Systems, Plants and Units

It may be interesting at this point to consider the size of utility systems, plants and units in terms of coal consumption.

Table I lists the 25 top-ranking coal-burning utilities for 1957, showing a total of over 100 million tons consumed that year. This is 65 per cent of the total quantity of coal used by the electric utilities in that period.

These figures are of course changing constantly, with substantial additions being made in many plants. The largest steam-electric plant in the world today is the Kingston Steam Plant of the Tennessee Valley Authority. In this plant there are nine turbines and boilers, four of them rated at 150 megawatts and five of them at 200 megawatts. This gives a total plant capacity of 1,600,000 kilowatts. Statistics of the "laid end to end" variety were never better applied than to this plant. If all the 50-ton coal cars required to maintain this plant at full capacity were laid end to end, the result would be one 350-car train coming into the plant every 24 hr. With this enormous quantity of coal being consumed, it is not surprising that a wide variety of coals is purchased, requiring considerable flexibility in the design and performance of equipment.

There has also been a marked increase in the size of individual units. Fig. 11 shows the largest steam generating unit bought in the U. S. to date. Now in the design stages, it will supply steam to a turbines rated at 500 megawatts. The turbine throttle pressure is 2400 psig and the boiler delivers 3,850,000 lb of steam per hour at 1050 F, with reheat at 1000 F. The boiler is of the controlled circulation type with two furnaces each 40 ft square. There are four regenerative type air heaters and ten 30-ton per hr pulverizers. Eight of these mills will normally handle full load, with the other two

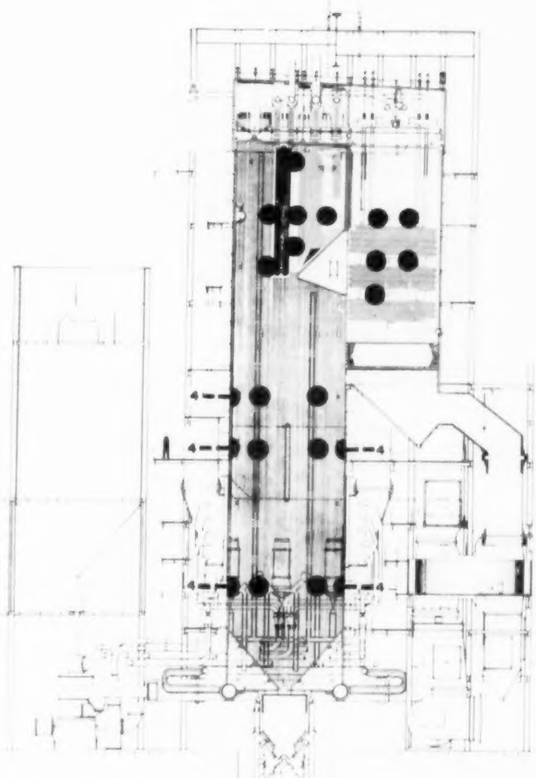

Fig. 8—Soot blower locations for a plant called "C" burning a midwestern bituminous coal

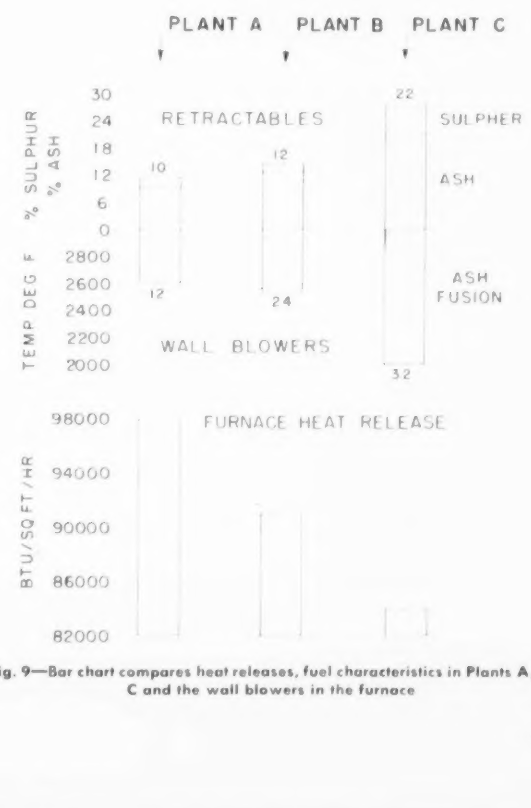

Fig. 9—Bar chart compares heat releases, fuel characteristics in Plants A, B, C and the wall blowers in the furnace

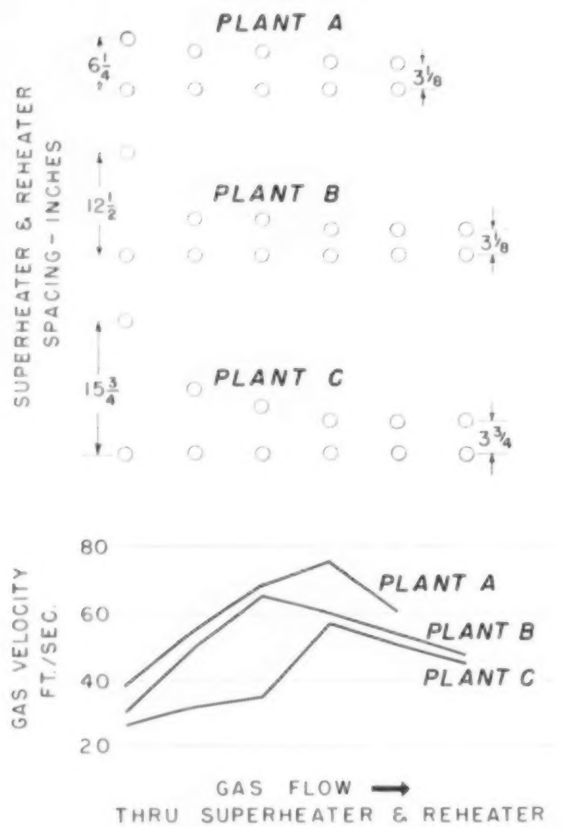

Fig. 10—Comparison of lateral spacings between superheater and reheater elements and gas velocities for Plants A, B, C

mills serving as spares. The total coal consumption is over 200 tons per hr.

Availability

In general, as unit sizes have become larger, the combined efficiency of the boiler and turbine has increased, and the cost per installed kilowatt has decreased. But large size can only be justified if availability is high, since outage of a 200 to 500-megawatt unit may mean a loss of many thousands of dollars per day. Fortunately, however, the record shows that availability has been increasing in recent years. Fig. 12 is a record of 125 units which have been in service from 1949 through 1957. Less than 1 per cent of outage time was caused by failure of or maintenance on pressure parts or fuel burning equipment.

Coal Preparation

It can be concluded that it is of the utmost importance that the coal buyer give attention to the quality of the coal whose burning characteristics compare unfavorably with our low volatile Pennsylvania anthracites. Cleaning operations are almost totally lacking, and the pulverizers must handle overburden containing crystals of garnet and quartz, commercial abrasives. Another foreign plant handles coal with an ash content of 35 to 65 per cent. In this case the plant capacity has actually

TABLE 1—COAL'S TOP-RANKING ELECTRIC UTILITY CUSTOMERS—1957

		Tons Consumed
1.	Tennessee Valley Authority	18,240,000
2.	Commonwealth Edison Co.	9,524,000
3.	Detroit Edison Co.	5,771,000
4.	Consolidated Edison Co. of N. Y. Inc.	5,170,000
5.	Appalachian Electric Power Co.	4,469,000
6.	Indiana-Kentucky Electric Corp.	4,198,000
7.	Ohio Power Co.	4,135,000
8.	Philadelphia Electric Co.	3,979,000
9.	Niagara Mohawk Power Corp.	3,880,000
10.	Pennsylvania Power & Light Co.	3,706,000
11.	Ohio Edison Co.	3,674,000
12.	Duke Power Co.	3,657,000
13.	Duquesne Light Co.	3,522,000
14.	Consumers Power Co.	3,451,000
15.	Electric Energy, Inc.	3,162,000
16.	Ohio Valley Electric Corp.	2,998,000
17.	Cleveland Electric Illuminating Co.	2,851,000
18.	Union Electric Co.	2,471,000
19.	Virginia Electric and Power Co.	2,402,000
20.	Public Service Co. of Indiana	2,394,000
21.	Alabama Power Co.	2,372,000
22.	Wisconsin Electric Power Co.	2,326,000
23.	Public Service Electric and Gas Co.	2,286,000
24.	Cincinnati Gas and Electric Co.	2,071,000
25.	West Penn Power Co.	2,015,000
	Total	104,767,000

been limited by the capacity of the ash handling system.

Glaring examples such as these are probably not representative. Nevertheless, even in the U. S., the raw material which reaches the surface of the earth is of poorer quality than in the past, and, paradoxically, this is largely due to modern mining methods. With full-scale mechanization, selective mining has given way to full-seam mining, which delivers much of the impurities with the coal. In addition, in strip mining, much of the overburden may be included with the coal.

If ash, sulfur and moisture are low, the only operation necessary may be sizing, by such processes as scalping, crushing, screening or hand picking. However, if ash and sulfur are excessive, some form of cleaning or washing is in order. This may increase moisture, and drying by centrifugal means or some thermal means as flash drying may be required.

Evaluation

The Edison Electric Institute reports that for 1957 the total operating expenses for all private utilities was over $3\frac{1}{2}$ billion dollars. Of this total, almost $1\frac{1}{2}$ billion dollars was for fuel, and over half a billion dollars was for maintenance. Much of this maintenance cost can be reduced if impurities in the coal can be at least partly removed before the coal is shipped.

Many utilities are evaluating impurities on the basis of incremental cost. Factors may include labor for maintenance, boiler efficiency, power consumption, soot blowing steam or air, fixed charges on added investment, and power replacement. Such costs may add up to \$1 to \$1.50 per ton of coal, whereas the cost of cleaning the coal at the mine may be a fraction of this. One Midwest utility found that there was as much as 25 cents per ton difference between the operating cost of an average coal and the cost of low grade coal. This represented 5 per cent of the price of the coal, enough to make them eliminate the poorer coal. Another utility uses a bonus-penalty method of coal purchasing. They

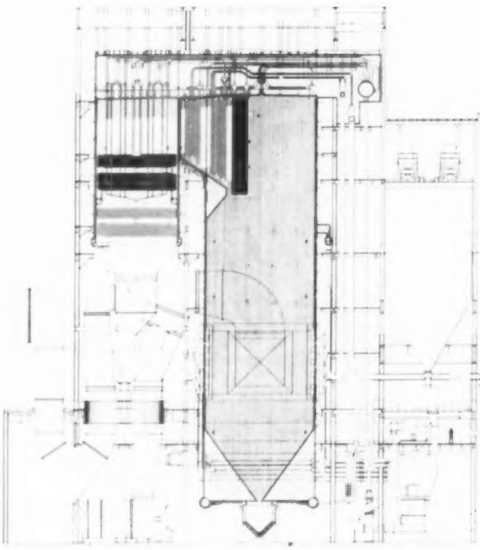

Fig. 11—Largest steam generating unit bought in the U. S. to date. It will supply steam to a 500-mw turbine at 2400 psig

REHEAT

AVAILABILITY STUDY OF ALL PRIVATE UTILITY UNITS

	1949 THRU 1957
Number of Units	125
Total Capacity_Mw	13,531
Average Capacity per Unit_Mw	111
Total Boiler_Hours	3,652,434
" " _Years	421
AVERAGE AVAILABILITY (BOILER)	95.51%
AVERAGE USE FACTOR (BOILER TURBINE)	90.15%
AVERAGE CAPACITY FACTOR (BOILER TURBINE)	93.79%

PER CENT TOTAL HOURS IN OUTAGE

INSPECTION	2.93%
BOILER _ SUPERHEATER REHEATER _ ECONOMIZER DESUPERHEATER _ FUEL BURNING EQUIPMENT	0.81%
AIRHEATER _ WASHING, ETC	0.20%
(Auxiliary Equipment) VALVES _ FANS _ SOOT BLOWER _ MISCELLANEOUS	0.57%
TOTAL	4.49%

C-E Post War Reheat Units	249
Total Capacity_Mw	33,775
Average Capacity per Unit_Mw	136

Fig. 12—Availability record for 125 units in service 1949 through 1957

have worked out a contract with their supplier which includes price corrections for moisture, ash and sulfur. Each coal shipment is sampled at the plant and the price for that shipment is adjusted in accordance with the percentage of these constituents.

Summary

Summarizing, we have noted that coal in pulverized form will be the major fuel for utility plants for a long time to come, and its use will undoubtedly increase. Impurities in coal affect the design, operation and cost of most of the components of a steam generating unit. With rising costs, increases in unit size, and greater need for high availability, designers and operators will be looking for better quality coals. It is thus incumbent on the coal producer to make available coals which have been better prepared and which are of more uniform quality over the life of the steam generating unit.

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Here is a well stated summation of the water problems besetting the return system of a steam power plant or a heating installation and should prove of special value to the industrial plant man

Oxygen and Carbon Dioxide Corrosion

By PAUL BRINDISI

Celco Laboratories

Along with scale, corrosion can be equally damaging to boilers. What's more it can be most troublesome in steam and returns system as well. Corrosion may develop from various causes, especially at high operating pressure, where this problem becomes quite intricate. However, here we'll consider the principal and more destructive agents of corrosion oxygen and carbon dioxide.

Sources

All waters absorb a certain quantity of air and subsequently, too, oxygen. This free oxygen neither reacts with water itself nor the salts in solution, but is carried along as a dissolved gas. The amount of oxygen present depends largely upon the prevailing temperature. Oxygen's solubility increases with lowering of the water's temperature. Longer contact time with the atmosphere also favors greater absorption of this gas. Consequently, all surface waters contain free oxygen. They may have any degree up to full saturation, which is approximately 14 ppm at 32 F and 10 ppm at 60 F.

Rain water has a strong tendency to dissolve carbon dioxide from the air. Then, in passing through soil, this water picks up other carbonic ingredients. As a result, subterranean waters normally have very little

REACTIONS:

oxygen, but are quite rich in carbon dioxide. Well waters may contain as much as 40 ppm of this gas, or even more under pressure. In surface waters, carbon dioxide will exist in variant amounts. However, it is generally fairly low and seldom exceeds the oxygen present.

Unlike oxygen, carbon dioxide does, in part, loosely unite with water. While carbon dioxide's solubility is likewise governed by temperature, it is also greatly influenced by the water's chemical ingredients. An acidic condition enhances the existence of free carbon dioxide, whereas an alkaline condition diminishes it. Oxygen is not so affected. Carbon dioxide can remain free so long as the water's pH is below 8.3. Above this value, the gas is completely absorbed in reaction with the alkaline constituents.

All waters possess hardness, which may be of the temporary form either in whole or to considerable extent. This hardness consists of the bicarbonates and carbonates of calcium and magnesium. With increased temperature, soluble calcium bicarbonate decomposes to release carbon dioxide and precipitate calcium carbonate, Reaction 1, Fig. 1. Magnesium bicarbonate does the same, only its unstable carbonate further breaks down into more carbon dioxide and magnesium falls out as hydroxide, Reaction 2, Fig. 1. In addition to these hardness salts, the water's natural alkalinity as sodium bicarbonate undergoes similar action, Reaction 3, Fig. 1. Every 100 ppm of bicarbonate produces 79 ppm of carbon dioxide and 100 ppm of decomposable carbonate furnishes 35 ppm of this gas.

Oxygen, therefore, reaches the boiler solely from gas dissolved in the feedwater. Carbon dioxide makes entry both as gas carried in solution and that evolved from decomposition of carbonates in the boiler water. These gases originate mainly in the makeup water, but occasionally enter with the condensate through air leaks in the returns system.

Corrosion

While water is very reluctant to dissociate, a minute portion does separate into its charged components of hydrogen and hydroxyl ions, Fig. 2. Iron is electrochemically more active than hydrogen. Because of this, an iron atom leaves the outermost molecular layer of the bare metal and displaces the weaker hydrogen from the ionized water. Iron combines with the remaining hydroxyl ions to form soluble ferrous hydroxide. Meanwhile, hydrogen replaces the departed iron on the metal surface and proceeds to gradually cover that affected area. This hydrogen blanket shields the metal from further action. Iron so lost is infinitesimal.

But oxygen causes this process to continue. Some oxygen unites with the protecting hydrogen to make water, Fig. 3. A second molecular layer iron is thereby exposed to renewed electrochemical reaction. Other oxygen converts soluble ferrous hydroxide into insoluble ferric oxide, which deposits out as rust. Water's limited capacity for dissolving iron is thus re-established. This action repeats as long as the oxygen supply lasts. Meantime, the metal becomes thinned down.

Carbon dioxide unites with water to produce carbonic acid, Reaction 4, Fig. 1. This weak acid dissociates more extensively than water, hence, is capable of furnishing hydrogen ions at a speedier rate. Moreover, formation of this acid brings a lowering in pH, which increases the solubility of iron.

Carbon dioxide, therefore, can accelerate the action of water upon a metal surface by many times. However, oxygen is far more aggressive. Its attack on iron could be as much as tenfold faster than carbon dioxide. And in their combination, oxygen's corrosive ability may be further quadrupled.

Effects

Oxygen soon reverts from an initial widespread attack to a concentrated one. Its destructive action will be worse where water undergoes a marked rise in temperature, due to the mass liberation of this dissolved gas. Oxygen peppers the metal surface with pinholes and works fastest at those offering least resistance. Once a good bite has been taken, the cavity is steadily expanded and deepened till the weakened metal ruptures. So it is that metal can fail from a small cluster of bad pit holes even while the surrounding area remains hardly damaged.

Oxygen is prone to act first wherever the metal does not present a tightly bound surface. Such places may be where its crystalline lattice is not uniform or the composition not homogeneous; where there exists microscopic metal flaws or breaks; where the metal suffers fatigue from continual expansion and contraction;

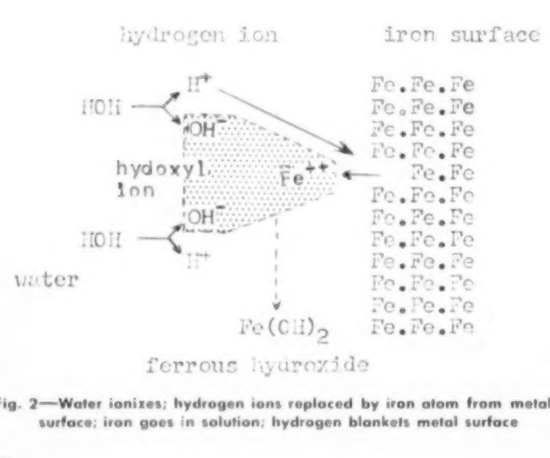


Fig. 2—Water ionizes; hydrogen ions replaced by iron atom from metal's surface; iron goes in solution; hydrogen blankets metal surface

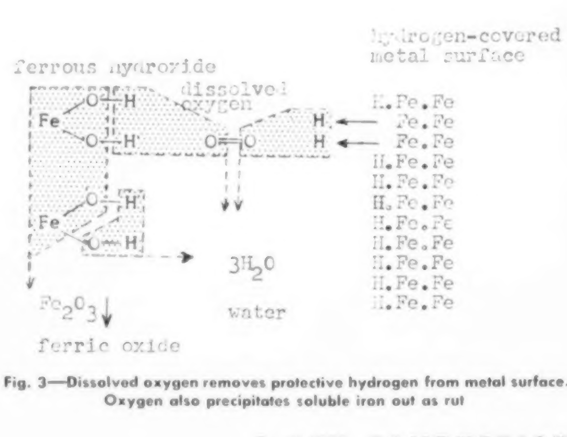


Fig. 3—Dissolved oxygen removes protective hydrogen from metal surface. Oxygen also precipitates soluble iron out as rut

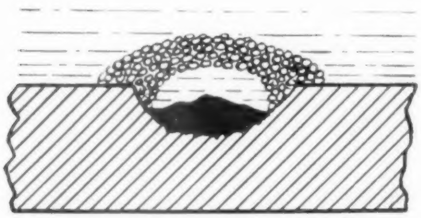


Fig. 4—Pit hole with rust dome and active magnetic iron core

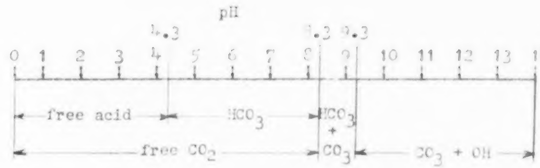


Fig. 5—Alkalinity changes and presence of free carbon dioxide with respect to pH

or where the metal is subject to considerable bending stress.

Where oxygen corrosion is heaviest, the adjacent water becomes quickly supersaturated with dissolved iron. This causes some unfully oxidized iron to leave solution as black magnetic iron, Reaction 5, Fig. 1. On complete oxidation of this deposit, the resulting rust particles are pushed to the rim of activity. Eventually, such crust builds up into a dome-shaped nodule, Fig. 4.

Red markings thus denote general corrosion. A small red ring with a black center speck shows the makings of a pin hole. And a rust nodule will invariably be covering a pit hole. So, too, presence of magnetic iron is indicative of active oxygen corrosion, whereas its absence usually signifies such action has been retarded or arrested.

Carbon dioxide in water acts more like an acid than a gas. As an acid, it spreads its attack over the entire exposed metal. The stronger this acidity, greater will be the consumption of iron. Carbon dioxide, hence, produces general corrosion with an overall thinning of the metal. Where this dissolved gas is heavily concentrated, accelerated erosion will cause grooves to develop.

Occurrences

In cold water, carbon dioxide is fairly passive, while oxygen displays subdued activity. Natural waters tend to lay a film of calcium carbonate inside pipes, which retards corrosion. The higher percentage in temporary hardness, the more secure will be this protection. Subsequently, we usually find only light general erosion in raw water lines.

Hardness remaining from lime-soda softening is normally of a moderate quantity, existing wholly as carbonate. Therefore, little corrosion is expected to follow. With exchange softeners, the residual hardness is virtually nil, so there develops no filming protection. Such softened water may be quite corrosive.

Receiving tanks, closed heaters and heat exchangers can suffer severe corrosion from a sudden elevation in water temperature. This brings about a localized concentration of liberated oxygen and carbon dioxide gases and consequently, too, their increased activity. Same may occur in an economizer, where more of these gases become rapidly expelled from the feedwater. Such action could also develop in the preheating section of some boilers, especially when incoming water is briefly detained within a restricted space.

In boilers, the first and more intense evidence of oxygen corrosion comes on pitting of the drum along its water-level belt. Much of the dissolved gas is released at the surface of boiling water. Then, too, water continually laps the shell sides, leaving intermittent thin sheets that evaporate readily and promote oxygen attack upon the metal. Furthermore, this area is almost always scale free.

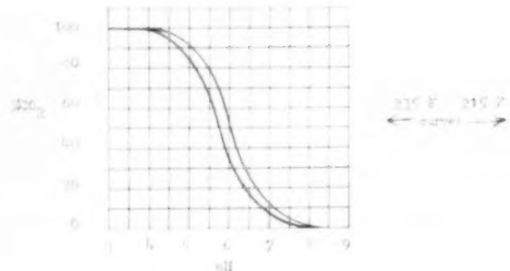
The rolled ends of tubes are quite vulnerable to oxygen corrosion, due to a weakening of the metal surface under stress. Sporadic pitting may also appear at points of main steam production. These could be on the furnace cylinder of an HRT package unit and in waterwalls or generating tubes of a water-tube boiler. Scale affords them much protection. Nevertheless, even the hardest scale will yield some to steam formation, thus providing openings for oxygen to reach the metal. Scattered pitting may well proceed amid a bad scaling condition. One such pit hole can cause a tube to fail long before it would have done so from the scale build-up.

With increasing heat and continued release of carbon dioxide, water acquires a pH of 8.3 prior to or soon upon entering the boiler. At this pH, some sodium hydroxide develops through breakdown of the water's natural alkalinity, Reaction 3. But hydroxide can't exist in the presence of free carbon dioxide, instead unites with it to reform bicarbonate, Reaction 6, Fig. 1. Equilibrium is maintained till more gas evolves wth heat and the disengaged hydroxide prevails. At 9.3, all the reabsorbed carbon dioxide is discharged and hydroxide comes into prominence, Fig. 5. Incoming carbon dioxide of fresh feedwater is thereafter held in check by the boiler water's concentrating alkalinity. Therefore, oxygen alone corrodes below-water sections of the boiler.

Some general corrosion may occur in the boiler's steam space on collection of condensate, particularly around steam-purifying equipment. Same holds for steam lines, where wet steam has its water droplets knocked-out at sharp bends or by regulating devices. Steel is not affected by either oxygen or carbon dioxide in dry steam. With high pressures, corrosion does develop in superheaters. But this is by direct action of steam on iron, not from attack by oxygen gas.

Oxygen and carbon dioxide resume their destructive action on redissolving in the condensate. General corrosion and pitting will be light where drips form. However, such activity intensifies as additional steam condenses and more gases are absorbed. A steam heavily laden with carbon dioxide will render the condensate strongly acidic. Grooving results when a pipe is partially filled with this rapidly flowing condensate.

When steam is entirely condensed, the line fills and all oxygen and carbon dioxide vapors are forced into solution. If overly saturated with these gases, the returns assume a very low pH and exceedingly high corrosiveness. The metal could then be badly thinned



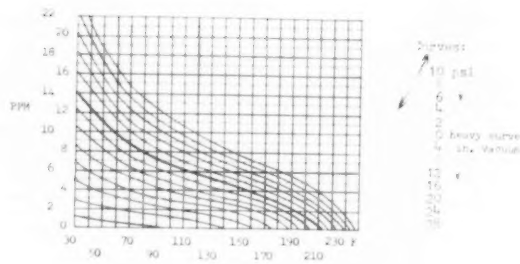


Fig. 6—Graph A: % CO remaining in solution with rising pH. Graph B: Oxygen solubility with increasing temperature and pressure

and gouged from a concerted attack by oxygen and carbon dioxide. Threads of piping and fittings readily give out, along with elbow walls.

Raw water ordinarily contains a small quantity of nitrogenous organics, which decompose in the boiler to liberate ammonia. This gas, on dissolving in the condensate, forms strongly alkaline ammonium hydroxide, Reaction 7, Fig. 1. While the ammonia passing off with steam is generally less than 0.5 ppm, it does help to neutralize some carbonic acid in the returns, thereby preventing its pH from dipping even lower.

Corrosion from carbon dioxide alone is relatively mild when it is below 6 ppm and the condensate's pH little under 7. But severe attack can be anticipated with carbon dioxide above 20 ppm and the pH below 5.8. Corrosion tends to subside as the returns cool down. At 150 F, such activity is usually half that at 200 F.

Oxygen, entering through air leaks in the returns system, greatly aggravates these conditions. Corrosion will be more pronounced in units where steam periodically undergoes complete condensation. Air may then be drawn in at intervals of unsustained vacuum. Air can also infiltrate through glands, gaskets, packing or water seals that fail to hold on steam or condensate-using equipment.

Deaeration

Corrosion is best countered with good deaeration of the feedwater. Since the solubility of both oxygen and carbon dioxide diminishes with increasing temperature, these gases can be eliminated from the water on boiling. Effective deaeration relies upon proper venting and maintaining the feedwater as close to or at the boiling temperature corresponding to the prevailing back pressure. This would be 224 F at 4 psi and 235 F at 8 psi.

In practice, water passing through a heater can't be sufficiently detained to insure complete removal of the dissolved gases. To hasten this action, the water is mechanically broken up so as to present larger exposure areas. Splashing over trays effects a greater expulsion of these gases than merely heating a vast bulk of water. Spraying the water proves even better. Still more efficiency is gained by forcing steam intimately through the water. By mass action, steam serves to physically displace much of the residual gases out of solution. Moreover, the uncondensed steam sweeps away the escaping gases, thereby reducing the vapor pressure each would have otherwise applied on the water surface. In so doing, the release of additional gases is rendered easier and, too, speedier.

Deaeration may be accomplished under vacuum as well, but not quite to the extent capable with a sprayed-water, positive-pressure type of unit. The latter can reduce dissolved oxygen to as low as 0.01 ppm. Such efficient heater operation will also produce zero free carbon dioxide, although not actually ridding the feedwater entirely of its original gas. This is because, on discharging carbon dioxide to within several ppm, the water invariably attains a pH of 8.3, at which point the remaining gas is reacted upon by the water's developed alkalinity. Therefore, some carbon dioxide always eludes removal, even with the best deaeration.

High boiler pressures demand the ultimate in deaeration. Oxygen is the more destructive of these two gases and also the one most likely to attack pre-boiler units along with the boiler proper. The less oxygen left in the heater effluent, the less need be its follow-up chemical correction. At those lofty temperatures, the injection of added chemicals must be restricted to a bare minimum, as increased salts may readily induce scale formation for foaming of the highly sensitive boiler water.

Ideal heater performance is not always economically or mechanically permissible with boiler systems of moderate-to-lower operating pressures. Limited heater storage space and periodic surges in feedwater demand can allow considerable oxygen and carbon dioxide to escape mechanical removal. Graphs A and B, Fig. 6, show their degree of discharge under various conditions. In any case, the water temperature should never be permitted to drop below 200 F. Otherwise corrosion in the feedwater system could be quite severe and the ensuing chemical correction costly as well.

Package boiler assemblies are often provided with only a receiving tank. This unit should be made to function as an open heater. It must first be adequately vented. Then it should have a perforated pipe arrangement extending over the bottom of the tank, through which steam is jetted into the water under thermostatic control.

Corrosion will be at its worst in systems where the condensate is returned directly to the boiler. Here there is no chance to free the returns of its redissolved gases. To those are added still more oxygen and carbon dioxide expelled from fresh makeup water entering the boiler. Result is that these gases cycle around the system in increasing concentration, bringing serious consequences to the returns piping and the boiler itself.

Correctives

Use of soda ash should be avoided or greatly minimized, whether it be for external softening or internal correction. Soda is chemically sodium carbonate, which easily decomposes with heat to yield carbon dioxide, Reaction 3, Fig. 1. Inasmuch as such gas is already dissolved in raw water and its alkalinity later breaks down to furnish more, it is superfluous to add another of this gas-producing chemical.

Water from an exchange softener can badly corrode an economizer. This unit could be safeguarded by feeding dilute caustic soda continuously to the heater effluent. Its pH should be maintained at 8.4 or better, if tolerable. Caustic renders inactive the remaining free carbon dioxide, Reaction 6, Fig. 1, and induces the residual hardness to lay down some carbonate film as protection against oxygen, Reaction 8, Fig. 1. An alternate method is to recirculate a trickle of boiler water bled from the continuous blowdown system. Either must be closely controlled lest the boiler be made too alkaline and excessive blowdown then be required to avert foaming or carryover. This becomes all the more difficult at higher boiler pressures.

Some plastic paints provide iron with good corrosion protection for cold or warm water. Tar-base paints prove more durable for boiling water. A newly installed receiving tank should be coated with such paint. And likewise, too, a badly pitted boiler drum. The latter must be wire-brushed down to bare metal for this paint to adhere lastingly.

Zinc rods are sometimes suspended in the boiler water to divert oxygen attack onto themselves and away from iron. Zinc is electrochemically more active than iron, hence, takes precedence in displacing hydrogen ion from the ionized water, Fig. 2. Zinc unites with the hydroxyl ions to form insoluble zinc hydroxide. Dissolved oxygen then works wholly at removing the protective hydrogen from the zinc surface, Fig. 3. Water loses its appetite for iron as long as the zinc lasts. However, under variant boiler operating conditions, it becomes pure guess as to when these rods are fully consumed. Should they not be promptly replaced, the boiler iron may be victimized instead. Moreover, this scheme is effective only at fairly low pressures and for small, whole bodies of water, such as with HRT boilers.

Chromates are occasionally employed for boilers, but they rightfully belong in cooling water systems. In the latter, such chemicals merely anodize the iron's surface. Under the more severe boiler conditions, they progress on, producing an extremely hard coating that greatly impedes heat transfer and curtails the metal's endurance.

A more common and reliable oxygen-remover is sulfite. It absorbs dissolved oxygen to convert into sulfate, another soluble form, Reaction 9, Fig. 1. By maintaining excess sulfite in the boiler water, oxygen of incoming feedwater is rendered inactive before this gas can be released. A sodium sulfite solution could be fed continuously to the heater's storage compartment or at the feedwater pump. While this corrective doesn't react instantaneously at below-boiling temperatures, such feed helps safeguard intermediate lines where these units are some distance from the boilers. Sulfited sludge-coagulating organics serve a dual function when incorporated with the phosphates of boiler water treatment.

About 10 ppm of sodium sulfite are needed for every ppm of oxygen. With good deaeration, the ensuing rise in dissolved salts is ordinarily tolerable for boiler pressures up to 300 psi. Higher pressures require proportionally lower boiler water solids, so also a decreasing sulfite reserve. Whereas a residual of 80 ppm is permissible below 300 psi, only 2 ppm dare be carried above 1000 psi. Table I shows recommended sulfite limits. Besides blowdown consideration, there is, too, the fact that some sulfite tends to decompose at high pressures, Reaction 10. Sulfur dioxide is discharged, which gas later dissolves in the condensate to form sulfurous acid, Reaction 11. It increases the acidity and corrosiveness of the returns. Therefore, sulfite necessitates closer control with rising boiler pressures.

Hydrazine is a new but effective oxygen-corrective. It consumes dissolved oxygen to become totally decomposed, producing water and inert nitrogen gas, Reaction 12, Fig. 1. There results no added salts, save a tiny residue that must be maintained. This should range from only 0.2 down to 0.02 ppm with mounting boiler pressures, see Table I. Hydrazine can't exist in any appreciable surplus under boiler conditions. Incomplete oxidation causes it to further break down and liberate ammonia gas as well, Reaction 13, Fig. 1. Such tendency increases with rising temperature. While little ammonia is beneficial for the returns, an excess brings dezincification of non-ferrous metals and pickup of objectionable copper.

Hydrazine's action on oxygen is considerably slower than sulfite, especially at the lower temperatures. Oxygen requires only an equal part of hydrazine. But the latter's easy decomposition and costliness demand of it limited use and an exacting control. Thus, this corrective is better suited for high operating pressures, where near-absolute deaeration is customary and the more favorable elevated boiler-water temperatures prevail. Here hydrazine is generally equal to sulfite both on performance and cost. A safe hydrated form of hydrazine can be fed in solution continuously to either the after-heater system or the boiler. Also like sulfite, the boiler water is readily tested colorimetrically for residual hydrazine.

With proper deaeration and chemical correction, zero oxygen can be insured for the boiler water. Oxygen attack is thereby prevented in the boiler and return line corrosion may be reduced as much as 90 per cent. Then remains whether additional cost for treating carbon dioxide is justifiable. If so, this can be accomplished with volatile neutralizing or filming amines.

Amines are ammoniated organics that are mildly alkaline. They vaporize with the steam whole, leaving no increased boiler water solids, such as otherwise was so with simpler ammonia-producing salts. Being weak alkalies, amines are easier regulated and not as damaging as ammonia. On dissolving in the condensate, a neutralizing amine combines with carbonic acid to form an inactive, soluble product, Reaction 14. Requirements for these amines vary from 1 to 5 ppm per ppm of carbon dioxide. And their governing pH may be between 7 and 9. Amines are apt to decompose and expel unwanted amounts of ammonia gas. Therefore, control relies on attaining the particular amine's most

TABLE I—RECOMMENDED RESIDUAL SULFITE AND HYDRAZINE WITH RESPECT TO TOTAL AND DISSOLVED SOLIDS FOR INCREASING BOILER PRESSURES

Psi	To 300	To 450	To 600	To 750	To 900	To 1000	Up
Total solids	3500	3000	2500	2000	1500	1250	1000
Dissolved solids	2500	2300	2100	1900	1430	1200	980
Residual sulfite	80	60	40	25	15	5	2
Residual hydrazine	0.20	0.15	0.10	0.08	0.06	0.04	0.02

effective pH while yet restraining its free ammonia.

Cost for neutralizing a high carbon-dioxide return is often prohibitive. Amines aren't recoverable, but lost on evaporation at the heater. Air seepage in the condensate defeats their purpose. More amine is consumed for the infiltrating carbon dioxide. Meanwhile, its accompanying oxygen corrodes return lines unattended, as such amines have no effect upon this gas. Filming amines could be employed instead. These tend to coat the condensate system with a water-repelling film. Because this lining is seldom uniform or unbroken, varying degrees of protection, up to 70 per cent, are obtainable. Since they hardly react with carbon dioxide, pH offers no control. Test pieces must be inserted at vital points to check that adequate amine build-up is developing where most needed.

Acidification

When the steam's carbon dioxide is persistently heavy, it will invariably emanate from excessive boiler water alkalinities. This may, in turn, stem from too high an initial alkalinity in the makeup water. Acid treatment of the feedwater then becomes necessary. Sulfuric acid is used to convert a precalculated amount of this water's sodium bicarbonate into carbonic acid, Reaction 15, Fig. 1. Aeration should follow to better expel most of the loosely held carbon dioxide prior to deaeration. Care must be exercised that the resulting sulfates can be safely sustained in the boiler water. Systems effecting partial or complete demineralization present no such problem.

First Fully Automated Electric Power Plant

Placement of the contract for an electronic computer control system to be the heart of the first completely automatic electric power generating station was recently announced. It was awarded to Daystrom Systems, La Jolla, Calif., a division of Daystrom, Incorporated, by Ebasco Services, Inc., consulting engineers, acting as agents for Louisiana Power & Light Company.

The electronic control system, which will make possible full automation, incorporates a solid-state, general-purpose digital computer to be installed at the new 225,000-KW Little Gypsy Station now under construction near New Orleans.

The new control benefits from experience gained at Louisiana Power & Light Company's Sterlington Station where, it is reported, a Daystrom solid-state operational information system containing some 4000 transistors and 7000 diodes has been in successful service without a single component failure for almost one year.

Automatic Start-Up and Shut-down

The computer will control start-up and shutdown of the Station, with $1^1/_2$ hours required for start-up. The plant will also go off the line immediately upon pushing the shutdown button. The start-up operation for a large generating unit according to Daystrom's general manager, C. E. Jones, must be conditionally and sequentially controlled and it involves about 800 steps in a typical start-up or shutdown.

It will be possible to instruct the computer to turn back or skip ahead to any other operational step. The system will monitor a large number of selected input signals continuously, and formulate alternative routes which could not be found using only conventional mechanical timers, sequential cams, and sensing relays.

There are approximately 700 points of inspection or actuation involved in the starting of a power station this size. The computer will scan and verify all on-off points and position indicators between each of some 800 total steps involved in starting or stopping the plant.

The procedures for hot or cold start-up, for complete shutdown, and for temporary shutdown and banking the boiler will be provided as automatic functions.

The automatic control system will perform all operations without human intervention. Manual operation will be required only in the event of a malfunction.

Automatic Plant Control

When the computer puts the station on the line it automatically reprograms itself and goes into operational mode. It runs the plant, operating these major control loops:

1. combustion control.
2. steam temperature control.
3. feedwater control.
4. spray control (overriding steam temperature control—a safety feature).

The installation includes a fuel safety and purge system. Upon any indication of an explosive mixture in the boiler, gas is shut off instantaneously and the boiler is purged with air. Necessary shutdown procedures are instigated immediately.

The computer continues to scan all inputs for over- or under-limit operation. If such is found and cannot be corrected by the system, visual, audible alarms and special print-out tell the operator exactly which point and how far it is off limits.

Every hour the computer does all computations on component efficiencies and overall efficiency, and measures important points of the system. All data are automatically logged. This information and information about any point in the system can be obtained upon demand by the operator at any time. The computer takes less than one second to do the calculations, but five minutes to log the data because of the mechanical lag of the typewriter.

By Dr. Ing. G. NOETZLIN, VDI
and Dipl. Ing. A. ENGL, Marl

First European Supercritical Power Plant: Design and Experience—Part II*

THE four types of austenitic steels used in the new power plant are listed in Table III. Based on the well known 18 8 chrome-nickel steels, these types have been modified by reducing the Cr-content and increasing the Ni-content in order to exclude as far as possible the embrittlement through the sigma phase during continuous operation at high temperatures.

A total of approximately 209 tons of austenitic material was used in the plant with 63 per cent being utilized in the steam generator and 30 per cent in the steam piping for the 4250 psig primary system and the 2000 psig first reheat system, as shown in Table IV. The steam turbines use comparatively little of this material due to their particular design.

The bulk of the austenitic material is made up of the two types having good welding qualities, X8 Cr Ni Nb 16 13 and X8 Cr Ni Mo V Nb 16 13. Certain parts in the topping turbine not requiring welding, were made of type X8 Cr Ni Mo B Nb 16 13. This steel containing boron in quantities which made it impossible to obtain acceptable welds, has the highest creep-rupture strength of all type 16 13 steels; its rupture strength was even considerably increased through warm and cold working.

The type X8 Cr Ni Mo V Nb 16 13 steel may be improved in its creep rupture strength by precipitation hardening to a level which is considerably above that of the simple type 16 13 steel (X8 Cr Ni Nb 16 13). This effect was utilized at the Huels plant. Only this particular steel in its heat-treated condition allowed the use of a 4250 psig operating pressure at metal temperatures up to 1185 F. Tests established that steels with vanadium content were subject to considerable scaling at temperatures beyond 1185 F and the heating surfaces were therefore distributed in the steam generator in a manner which avoided a higher wall temperature for any tube under normal operating conditions.

Austenitic steel is utilized in the Huels steam generator at tube wall temperatures beginning at 950 F. This is due to the combination of high pressure and high temperature which requires heavy wall thickness. The relationship of these wall thicknesses to the tube diameter makes thermal stresses a factor to be seriously considered. Use of higher quality steel quite often allowed thinner walls and thereby achieved a cost advantage even though the higher quality steel had a higher unit weight price.

These considerations were valid not only in locating the transition from surfaces with ferritic tubing to such with austenitic tubing, but also for the selection of the basic 16 13 Cr-Ni-steel vs. the hardening steel X8 Cr Ni Mo V Nb 16 13. This reasoning prompted the use of X8 Cr Ni Mo V Nb 16 13 for all tubing and headers at temperatures beyond 1030 F. In the temperature range between 980 F and 1030 F use of the higher quality steel was also of advantage for heavier piping and headers. For tubing in this temperature range, however, use was made of both grades of the 16 13 type steel.

A telling example of these considerations are the two reheat steam lines from the first reheater to the condensing turbine. For an outside diameter of 9.5 in. use of the heat treated grade of 16 13 steel required a wall thickness of 0.630 in. If these pipes had been made from the basic grade of 16 13 steel, their cost would have increased because of the requirements for a heavier wall.

All parts were heat treated at the mills according to the mills' own specifications. Parts made of steel X8 Cr Ni Mo V Nb 16 13 were subjected to 1380 F for five hours. If after cold working or welding of this grade a stress annealing or a repeat precipitation hardening was considered suitable, the parts were heated locally to 1470 F for 1 1/2 hours at most. This treatment was accepted by the mills because tests had shown that this type of heating did not yet produce any unfavorable changes in structure. This decision was of considerable practical importance since it would have been extremely

TABLE III COMPILATION OF AUSTENITIC STEELS USED AT POWER PLANT HUELS

Specification	C	Cr	Ni	Mo	V	N	B	Nb
X8CrNi Nb 16 13	0,1	16	13					10 × %C + 0,4%
X8CrNi MoNb 16 16	0,1	16	16	1,6 to 2,0				10 × %C + 0,4%
X8CrNi MoVNb 16 13	0,1	16	13	1,1 to 1,5	0,6 to 0,8	0,1		10 × %C + 0,4%
X8CrNi MoBNb 16 13	0,06	16	13*	1,8		...	0,05	10 × %C

* Recently increased to 16% Ni in specification X8CrNiMoBNb 16 16.
NOTE: Nb (Niobium) is the symbol used in Europe for the element known in the Anglo-Saxon countries as Columbium, Cb.

* Summary of two papers presented at the annual meeting of the "Vereinigung der Grosskesselbesitzer" (Association of Power Boiler Operators, VGB), in Bremen, 1958. Part I appeared in COMBUSTION, March 1959, pp. 43–47.
The full text was published in the magazine of the Association, No. 55 (1958), pp. 230–264. The summary was published in "Brenstoff Warme Kraft" (BWK), Vol. 10, No. 10 (October 1958), pp. 481–487 and was translated from the German by **Dipl. Ing. W. W. Schroedter,** Combustion Engineering, Inc.

Fig. 6—Boiler tubes damaged by alkaline infiltration—Left: tube from power plant boiler, Right: tube from experimental boiler.

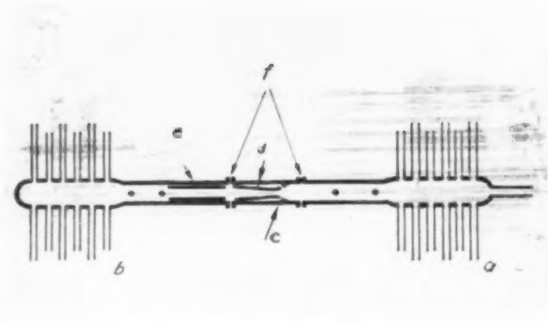


Fig. 7—Injection Desuperheater I. (a) Steam entering (b) Steam leaving (c) Water injection (d) Nozzle (e) Liner (f) Clamped connection.

difficult especially on the job site, to maintain a temperature of exactly 1380 F over five hours.

Tubes with outside diameters from 1 1/4 in. to and including 2 3/4 in. were cold bent without heat treating the bends. Connecting pipes with larger diameters were hot bent with subsequent annealing. The bends of the six 4250 psig primary steam lines with 4.77-in. O.D. and 0.866-in. wall thickness from the hardening grade 16 13 steel were formed at 1470 F within a maximum of one hour for each bend. If a higher forming temperature had been required, it would have been necessary to anneal the bent pipe sections with considerable difficulties involved in the operation because of the sections size and weight.

Welding Procedures and Post Heat Treatment

A special selection of welding procedures, filler materials and welders as well as an extensive inspection system were reponsible for satisfactory welding of austenitic material despite various difficulties. Weld seams of 16 13 steels cannot be expected to be completely free of cracks. Micro-cracks which even in continuous service will not lead to any serious trouble, were found to exist especially in the root pass. In selecting the filler materials not every charge was found to be equally satisfactory. Cracks in the seams of multi-layer weldments were most thoroughly eliminated if every pass was smoothly ground and checked with a magnifying glass.

In general backing rings were used for the root pass. These backing rings consisted of ferritic steel for all austenitic tubes and pipes. They were removed from the finished system by acid washing, which dissolved the ferrite but did not attack the austenite. Segmented copper rings were used for the steam piping. These rings improved the root weld by damming the inert gas and at the same time maintained the inside area at an acceptable level.

The tubes were welded to each other by the argon-arc process and to the headers by metal arc. The root pass of link piping was welded with argon-arc followed by electric welding for all other passes. The steam pipes were welded electrically throughout. The use of inert gas on the inside during electric welding of the root pass proved to be of advantage especially if it was necessary to make an exception and weld without backing rings.

It was carefully considered whether cold worked and welded parts should not be annealed in order to safely avoid the danger of stress corrosion which always threatens austenitic steels. In this respect a post heat treatment would have certainly been an advantage. However, after comparing the considerable cost of annealing to the possible success which must always be considered limited in regards to austenitic material, it was decided to anneal only the weld seams and cold worked bends of the heavy wall piping as well as the welds in the headers made of the hardening grade 16 13 steel. The basic 16 13 steel was heated to 1650 F for one hour. The hardening grade of 16 13 steel was treated to a heat of 1470 F for one hour.

The decision to forego any extensive heat treatment was all the more acceptable because the feedwater was to be demineralized to an extent which reduced its electric conductivity to less than 0.3 μS. Experiences to

TABLE IV WEIGHT OF AUSTENITIC STEELS USED IN POWER PLANT HUELS

	Specification	Weight Tons (Short)
Steam generator (including first stage reheater)	X8 Cr Ni Nb 16 13	31.4
	X8 Cr Ni Mo V Nb 16 13	99.5
	X8 Cr Ni Mo Nb 16 16	Slight
Steam piping (4250 psi and 2000 psi systems)	X8 Cr Ni Mo V Nb 16 13	62.6
Topping turbine (4250 psig)	X8 Cr Ni Mo 3 Nb 16 13	6.5
	X8 Cr Ni Mo Nb 16 16	5.6
	X8 Cr Ni Mo V Nb 16 13	1.9
	X8 Cr Ni Nb 16 13	1.2
Condensing turbine (1560 psig)	X8 Cr Ni Mo V Nb 16 13	Slight

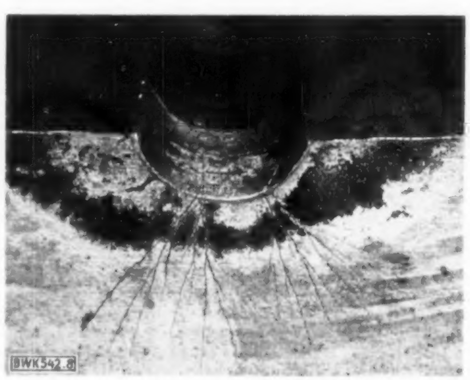


Fig. 8—Cracks by stress corrosion of the sharp bare edge of a welded vent

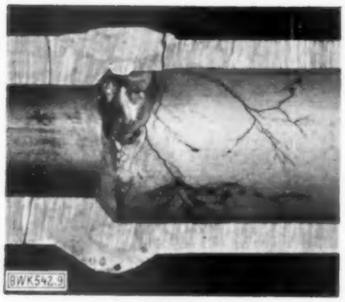


Fig. 9—Test weld in tube assembly section with stress corrosion at the abrupt change of cross-sectional material.

Fig. 10—Tube section with welded support lug and stress corrosion at the weld seam.

date indicate that stress corrosion is not to be expected with water of such purity.

Damages

If by a malfunction feedwater with higher salt concentration is allowed to enter the steam generator, stress corrosion is bound to occur. The intensity of the damages by cracking will differ according to how far any heat treatment was able to remove stresses.

The infiltration of sodium hydroxide into the feedwater after 3000 hours of operation demonstrated this assumption. In addition to the damages described earlier, a careful examination also revealed cracks which had not yet led to tube failures. The salt had penetrated the protective tube layer and cracking by stress corrosion followed very quickly. The influence of the Cl ions contained in the alkaline solution, on the mechanics of the corrosion was not determined.

The critical area for depositing was situated in the two sidewalls of the second gas pass. The heaviest damage was therefore sustained in that area with cracking in weld seams only. No cracks were found on cold formed bends. A corroded weld seam from a sidewall tube is compared in Fig. 6, with one from the test boiler.

A number of connecting tubes with $2^1/_2$ in. O.D. sustained very fine cracks due to stress corrosion in the cold formed bends. The cracks already penetrated the full wall thickness of 0.236 in. to 0.315 in. although they were only a few inches long. The damages due to

stress corrosion were also serious in the mixing pipe sections of the injection stage I, as shown in Fig. 7. Both injection heads strangely enough remained intact. The mixing sections, however, with the exception of those parts covered by the injection nozzles and liners, were damaged. The stress corrosion was especially strong wherever there were sharp edges of borings or at abrupt of cross-sectional area. Characteristic views of such damages are shown in Figs. 8 through 10.

Other operational damages to austenitic parts are important in regards to evaluation of their service in the power plant. The high sensitivity of the austenite against thermal shock was demonstrated by the rupture failures in two injection desuperheaters. Cracks developed within a short time in the nozzle head at the ligaments between the threaded borings for the water injection nozzles as shown in Fig. 11. Desuperheaters from austenitic material always appear to present a difficult problem, especially with large water quantities.

Small tubes welded to headers, Fig. 12, were subject to cyclic bending stresses due to a back and forth movement and tore off after 7500 hours of operation. This failure emphasizes that wherever possible, nipples with gradual change of cross-sectional area should be used to join thin tubes to heavy walled headers. If the thin tubes are welded directly to the header, the weld seam should at least be concave and notch effects avoided.

Experiences to date indicate that materials themselves do not offer any serious difficulties to power plant operation with supercritical pressures. It is, however, very important to give sufficient attention to the special qualities of the materials used during the design as well as during erection and later operation.

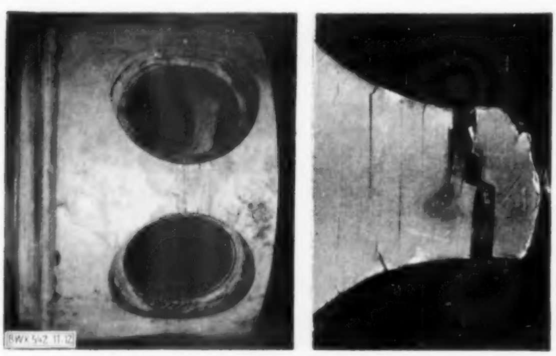


Fig. 11—Cracks due to thermal shock at the nozzle head of an injection desuperheater. Left: View of nozzle head (nozzle removed) with cracks in ligaments between nozzle openings. Right: Close up view of torn ligament.

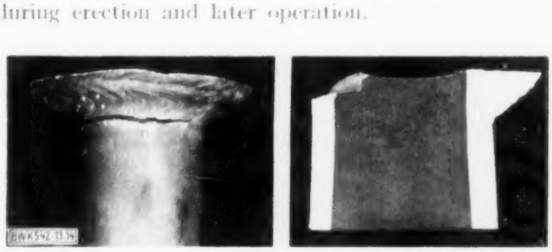
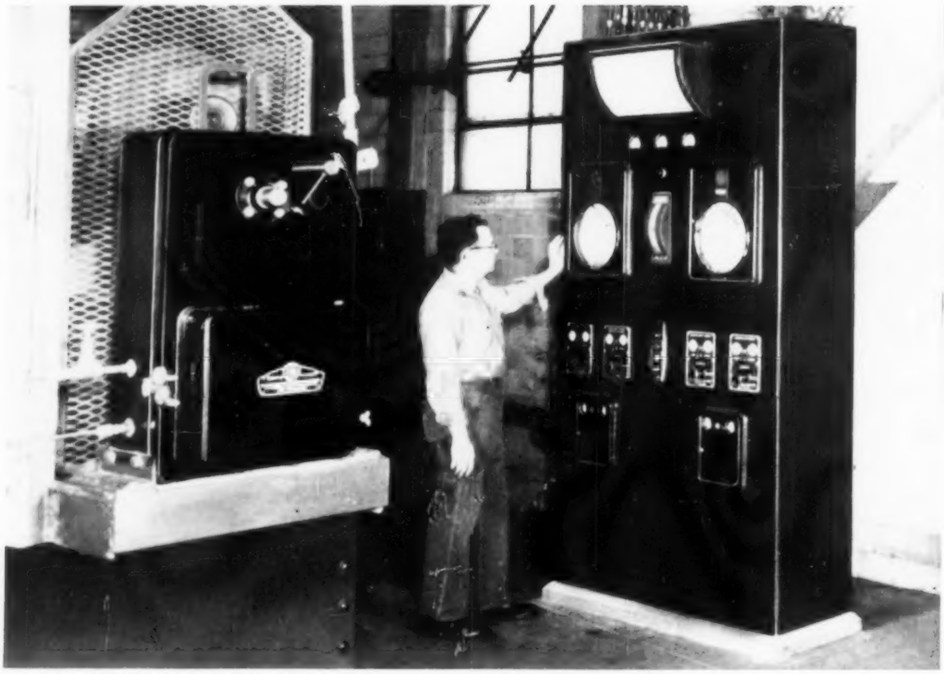


Fig. 12—Thin walled tubing welded to a heavy header and cut at base of the weld showing circumferential cracking



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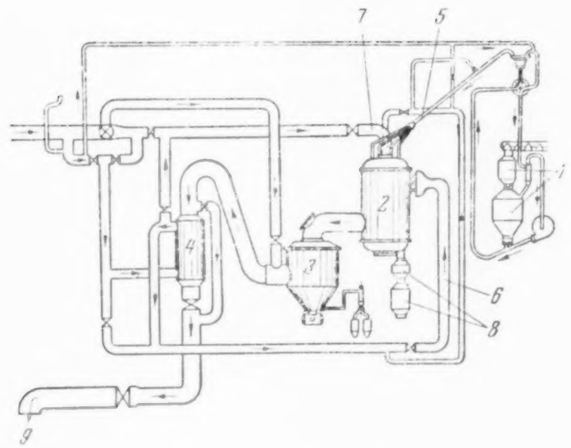


Fig. 1—Test stand arrangement

1—A sluice arrangement for coal dust *2* Combustion chamber *3* Ash and dust collector
4 Air preheater *5* Air-coal mixture *6* Secondary air *7* Tertiary air *8* A sluice arrangement for slag *9* Gas discharge into the atmosphere

The needs to exploit and apply formerly marginal fuels to keep up with energy growth exists the world around. Here is a Russian experiment on slag-tap firing of a Donets Basin coal.

Testing an Air-Cooled Slag-Tap Vertical Combustion Chamber*

By L. A. BOGDANOV† and B. D. KATZNELSON‡

A COMPARATIVELY large number of articles have appeared in recent years on the performance of slag-tap cyclone combustion chambers installed with various size steam boilers.

In this type of installation the use of a large quantity of water as a cooling agent for the cyclone combustion walls is undesirable. In the first place the combustion chamber in which the powdered coal burns operates on an open cycle. These installations are further peculiar in that they require the burning of the fuel under very high pressures.

This article presents the constructional peculiarities and the test results of a special stand, Fig. 1, working under a pressure of 4 atm abs and using powdered coal.

The combustion chamber, Fig. 2, is a slag-tap, vertical cyclone chamber with a gas outlet at the lower portion, shown as "5" in Fig. 2, and with the fire walls air-cooled. Water for cooling was employed only on the combustion chamber roof and at the gas outlet. The burning of the powdered coal takes place in the vertical cylindrical space. The heated secondary air which in quantity is 90 per cent of all the air used for combustion is forced at a high velocity through the tangential slots of the upper portion of the cylindrical space, identified as "9" in Fig. 2. The powdered coal is fed with a small amount of the primary air (around 10 per cent of the total air used for combustion) through six powdered coal ducts in the furnace crown around the periphery, identified as "8" in Fig. 2. The roof and the wall of the combustion chamber is cooled by tertiary air, "10" in Fig. 2, which in quantity is several times greater than the sum of the secondary and primary air. After cooling the combustion chamber this tertiary air enters the mixture or mixing chamber, "6" in Fig. 2 immediately below the furnace gas outlet, "5," where it mixes with the combustion products and lowers the exit gas temperature to an operating level (700 C).

An OK-500 axial blower supplies the fresh air which enters the blower at a temperature of approximately 85 C. By controlling the quantity of this incoming air which serves as a transport medium for the coal the powdered coal consumption can be limited to 750 kg/hr at the combustion chamber. A portion of this total air, 6000–7000 kg/hr for use as secondary air, is preheated by the exhaust gas up to temperatures ranging from 300 to 350 C in the air preheater pictured as "4" in Fig. 1. The remaining 20,000–23,000 kg/hr of air for primary and tertiary needs is led to the combustion chamber without preheating.

The chamber has three casings: outer, inner and intermediate. The outer casing is made from carbon steel in the form of a cylindrical container with a forged bottom and a roof capable of withstanding the internal pressure. The intermediate casing restricts the volume through which the tertiary air moves and on its exterior side carries the thermal insulation.

The inner casing has extended over its entire surface

* Translated from Issue No. 11, 1958, of the Russian publication *Teploenergetika*, pp. 14–20, by V. A. Ferencko, Combustion Engineering, Inc.
† Engineer.
‡ Candidate of Technical Sciences, Central Boiler Turbine Institute.

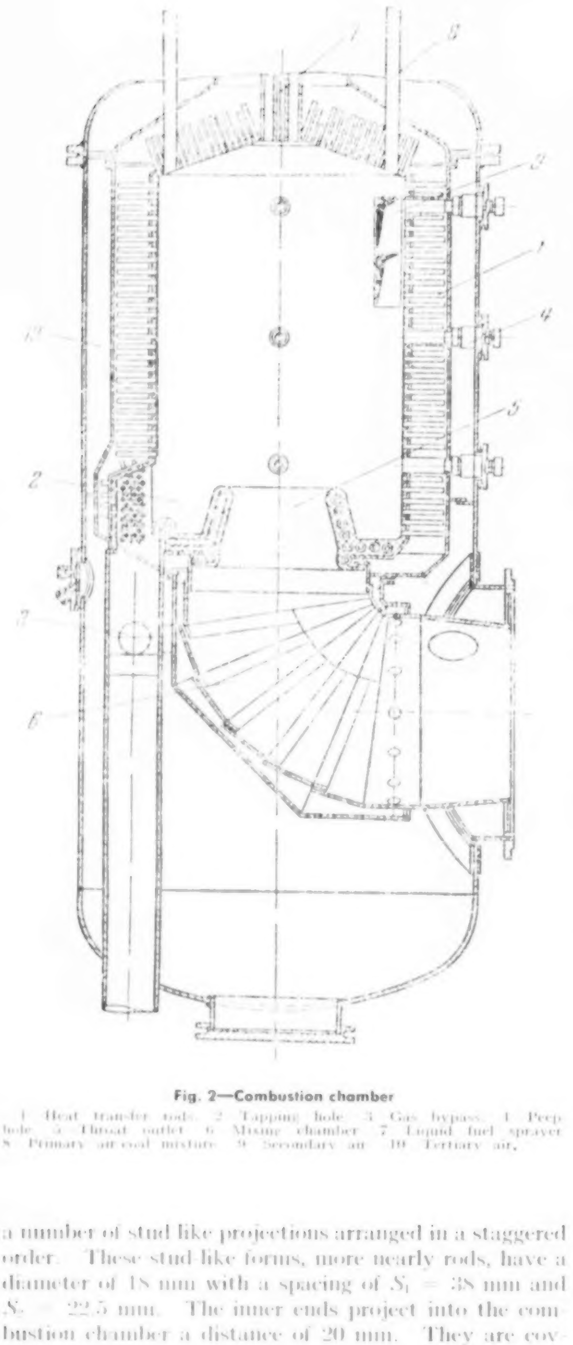


Fig. 2—Combustion chamber

1 Heat transfer rods 2 Tapping hole 3 Gas bypass 4 Peep hole 5 Throat outlet 6 Mixing chamber 7 Liquid fuel sprayer 8 Primary air-coal mixture 9 Secondary air 10 Tertiary air.

a number of stud like projections arranged in a staggered order. These stud-like forms, more nearly rods, have a diameter of 18 mm with a spacing of S_1 = 38 mm and S_2 = 22.5 mm. The inner ends project into the combustion chamber a distance of 20 mm. They are covered by a thermal insulation. The opposite or outer ends of the rods project on the outside of the fire walls a distance of 175 mm and are cooled by the tertiary air. This air which makes a single pass has a speed of 5 meters/sec where the excessive pressure equals 3 atms. The rods of carbon steel are held on from the combustion side by heat resistant electrodes. Bimetallic rods with heat resistant casings, and filled with cuprite, are set in the chamber roof. They measure 12 mm in diameter and have a spacing of S_1 = 38 mm and S_2 = 29 mm.

A liquid fuel sprayer is located in the chamber roof. When lighted it heats up the combustion chamber and the test stand. Electric arcs ignite the liquid fuel. At the chamber's bottom exit there is an outlet throat, 400 mm diam, "5" in Fig. 2, which permits the gases to discharge into the mixture chamber, "6" in Fig. 2.

The discharge or outlet throat is cone-like in appearance and protrudes up into the combustion chamber. A groove encircles the outside bottom edge of the cone and into it the liquid slag runs off from the fire walls. The slag then drains out of the groove into a slag catcher channel through a tapping hole. The tapping hole measures 300 mm by 300 mm and is located on one side at the bottom of the vertical wall. A sluice arrangement consisting of two slag hoppers and two valves is used for draining the slag.

A compartmented drum type feeder supplies the powdered coal. This feeder works from a hopper filled by a sluice arrangement involving an auxiliary bunker and two coal valves.

Adjusting the Combustion Chamber and Its Separate Elements

Liquid fuel (petroleum) serves to light off the unit and to heat up the combustion chamber. When the secondary air reaches 150 C the powdered coal is admitted. There is a few seconds elapsed before the transition from oil to a self-sustaining coal fire is achieved.

To obtain a reliable liquid slag removal it was found necessary to adjust the tapping hole and the slag catcher arrangement. The original tapping hole design proved unworkable. Clots appeared in the liquid slag stream flowing off from the groove. These clots caused partial spattering on the walls of the slag catcher channel and led to clogging of the tapping hole itself. A baffle, Fig. 3a, eliminated this clogging defect at the tapping hole in such a way that a pool 60–80 mm deep forms in the groove. (The slag clot formations were eliminated in the same manner.) Further any slag that spills over the baffle breaks off from it and falls into the sluicing water not touching the walls.

A bypass of a small amount of gas from the combustion chamber into a line to warm up the tapping hole was effected, "3" in Fig. 2. This step plus that of the baffle in Fig. 3a allowed the main stream of liquid slag to flow out satisfactorily. A sluggish movement of slag still occurred along all the flat walls of the tapping hole (on the sides and on the roof wall) and would form a solid, overhanging clot. The solution seemed to be a baffle with a precipice on all sides and not only on one side as in Fig. 3a. This assumption was proved on a small experimental chamber, Fig. 3b.

In addition to the tapping hole difficulties the original design of the slag catcher proved similarly unworkable. The slag clogged in the inclined flow passages under the surface of the water. The valves in the sluice lines projected into the runways or guides and the slag would plug up around them. As a corrective measure the slag catcher pipe was installed vertically and the valves made in the shape of a folding plate with a rubber contraction. This arrangement proved its reliability in many tests.

Once a stable operation for liquid slag removal was achieved the basic combustion chamber operating defects were studied. These defects were principally slag formation in the mixing chamber, slag deposition in the combustion chamber air admission slots and a scouring or washing out of the fire wall refractory coatings.

Originally the mixing chamber was constructed in such a way that the tertiary air for cooling the gases down to operating temperature entered through several rows of 40-mm diam holes. These holes filled up with slag accumulations and made the mixing chamber inoperative. About 20 per cent of the slag leaving the combustion chamber departs through the throat outlet together with the gases. A portion of this slag flows along the surface of the throat outlet in liquid form. Nearing an opening through which the relative cool tertiary air is entering the liquid slag cools becoming sticky and hard and thereby forming solid slag deposits. This solid deposit tends to grow as more slag comes into contact with it.

The mixing chamber, then, was altered and took on the form shown in Fig. 2 on the basis of results obtained in a specially conducted test. In this new design the tertiary air comes out through several narrow slots directed lengthwise along the mixing chamber wall and creates a protective screen against slag deposition on the walls. A small part of the tertiary air enters the mixing chamber through a circular row of round openings and this flow equalizes the temperature over the cross section of the exit gas path. The velocity of the tertiary air in the slots and openings equaled something more than 15 meters/sec. The distance ratio to the width of the slots was set at 15:1.

At the top of the mixing chamber at the throat outlet an abrupt increase in the diameter takes place. This insures a break in the stream of liquid slag as it discharges from the outlet walls of the throat and provides for a cooling of the slag in its flow. The redesigned mixing chamber has always been found to be clean after tests with no slagging evidence even after lengthy tests.

Slag is also deposited at the admission point of the secondary air entering the combustion chamber. It proved to be a serious drawback and limited the length of uninterrupted operation. Its occurrence can be explained in the following way. The inlet point of the secondary air across the slots, "9" in Fig. 2, on the fire wall is a significant low temperature area. Particles of liquid slag moving along the fire walls in that area and likewise particles thrown out of the gas stream as a result of its revolving motion experience a lowering of their temperature in the area of the slots to where they lose their liquid state and deposit out on the fire walls near the slots. As the deposits build up they tend to partition off or channel the path of the secondary air leaving the slots. To eliminate this deposit problem tests were made on a small capacity chamber and many designs were tried in the battle.

A cup-like arrangement, Fig. 4, gave encouraging results in this test work and it was selected for operation. Its essence consists in the following: the cup-like device is riveted onto the combustion chamber roof and juts into the combustion area forming around itself an annular or ring expanse. The preheating and fuel premixing takes place within the cup with some partial burning possible within the cup. Under the conditions within the cup, however, the ash fusing temperature is not reached and further the crushed coal-air mixture stream does not contain any particles of a size that could stick to the cup walls so slag deposits do not occur there.

A smooth metallic surface is attached to the vertical fire wall of the main combustion chamber from the roof

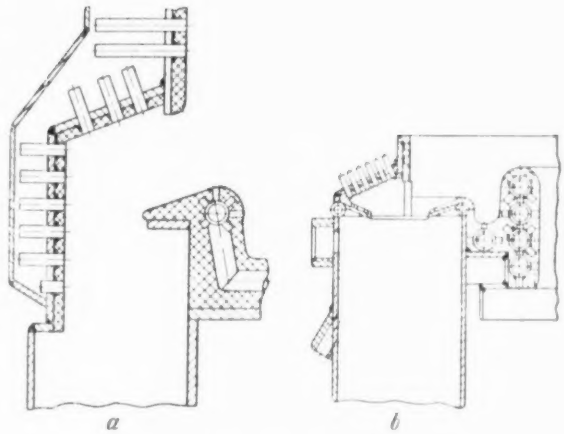


Fig. 3—The tapping hole arrangement

a—After alteration. *b*—Tapping hole of a small experimental chamber.

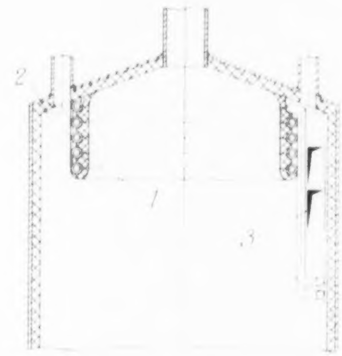


Fig. 4—Cup arrangement with annular area

1—Cup. *2*—Annular area. *3*—Secondary air slots.

down a vertical distance of about half the circumferential length of the chamber.

The cup and its surrounding annular area decreased the formation of slag deposits at the secondary inlet air slots. After recurrent tests inspections of the chamber showed but small slag deposits at the edges of the slots. The deposits weighed in all about 3.5 kg and their growth did not depend upon the length of the test which indicated the deposit growth would not limit the duration of the test.

After the cup had been installed certain changes were observed in the operating results. If, prior to the installation, the combustible content in the slag as a rule was equal to zero, after installation fragments of coked, crushed coal measuring up to 10 mm appeared in the slag. Further, it was observed that the combustible content in the slag varied with the vertical height or the distance the cup reached into the combustion chamber. In the first five tests combustible content in the slag equaled 10 to 23 per cent. After the cup height was lowered this combustible in the slag dropped to 2 to 5 per cent. It must be kept in mind that mechanical failures to light off the fire were extremely small and hence did not contribute appreciably to the combustible content in the slag as is shown in Table I.

TABLE I—RESULTS OF THE COMBUSTION CHAMBER TEST

	Number of Tests										
	1	2	3	4	5	6	7	8	9	10	11
Pressure in the mixing chamber P, atmosphere pressure	2.87	2.73									
Ash content A^p, %	9.29	11.08									
Grindability											
R_{75}, %	40.8	47.0									
R_{250}, %	3.5	8.8									
Fuel consumption B, kg/hr	635	680									
Exit speed of the secondary air at the slot w_{slag}, m/sec	106	102									
Mechanical failure to light q_4, %	0.31	1.05									
Slag catcher coefficient $K_{slag\ catcher}$	0.9	0.84									
Excessive air coefficient											
In the combustion chamber α_2	1.09	1.01									
After the mixing chamber α	4.3	4.39									
Furnace volume stress due to temperature change, Q_1/V, 10^6 kg cal/m³ hr	4.24	4.41									
Cross section stress due to temperature change Q_1/S, 10^6, kg cal/m²/hr	5.44	5.66									
	First Lot Coal					Second Lot Coal					

The coked particles appearing in the slag probably form within the cup. This phenomenon can possibly be best demonstrated by the following explanation. The annular area isolates the cup walls from any reverse currents from the central part of the combustion chamber. As a result the temperature within the cup has a lower temperature than that within the main chamber. Visual observations through the peep hole, "4" in Fig. 2, showed the conspicuous flame flashes had temperatures up to 1100 to 1300 C according to an optical pyrometer reading. CO_2 readings according to a gas analysis registered 1 to 3 per cent with O_2 at 18 to 20 per cent attesting to a large, local excess air supply. The low temperatures probably not only delay ignition but also cause coke formation.

Final conclusion on the operating effects of the cup and its ring cannot be made on the basis of the present work. More detailed studies have been planned including those on the selection of the sizes for the cup and the annular area within a specially devised small experimental cyclone combustion chamber. Nevertheless it is evident that the use of a cup and its attendant annular area in the described space gave positive results in the fight with slag deposits at the secondary air inlet slots.

The thermal expansion of the combustion chamber casing was the subject of a special survey because of the design difficulties this expansion creates for the component parts which tie together the chamber casing (the exterior and the fire wall surfaces). In the combustion chamber the skin casing rests on cantilevers welded to the outer walls in the lower section approximately at the tap hole level. The thermal expansion then is directed toward the top and reaches its maximum growth at the top of the casing. Tests showed that the transfer of heat begins immediately from the time of lighting the liquid fuel. The greatest heat transfer rate occurs when the combustion chamber is operating with a liquid slag removal. At this rate of heat transfer thermal expansion amounts to 13 mm. Further designs of the vertical cyclone chamber at the Central Boiler-Turbine Institute employed skin casing support points at the top of the combustion chamber to eliminate skin casing expansion in the area of the slots.

Thermal Characteristics

The tests of the vertical cyclone combustion chamber were carried out with Donets Basin gaseous coals. Two lots were obtained sharply differing from each other in elemental composition especially as regards the lowest ignition point, ash content and volatile content.

The composition of the first lot of coal was Q^p = 6310 kg cal/kg; W^p = 9.63 per cent; A^p = 8.35 per cent; S^p = 2.28 per cent; C^p = 66.18 per cent; H^p = 4.44 per cent; $O^p + N^p$ = 9.12 per cent; V^r = 43.32 per cent.

The composition of the second lot was Q^p = 5854 kg cal/kg; W^p = 7.57 per cent; A^p = 16.82 per cent; S^p = 2.34 per cent; C^p = 61.09 per cent; H^p = 4.18 per cent; $O^p + N^p$ = 9.00 per cent; V^r = 38.32 per cent.

The two coal lots differed little in ash fusion temperature characteristics which for the first lot was: t_1 = 1125–1140 C; t_2 = 1200 C; and t_3 = 1300–1360 C; and for the second lot t_1 = 1120 C; t_2 = 1190 C; and t_3 = 1330 C.

Table I shows the test results.

Fuel consumption during the tests ranged from 560 to 725 kg/hr. The top fuel rate was limited by the amount of transport carrying air available for the powdered coal feed. The grindability of the coal equaled R_{75} = 25 to 48 per cent. The furnace heat release amounted to 4.85 × 10^6 kg cal/m³/hr and the corresponding cross-sectional heat release totaled 6.25 × 6.25 × 10^6 kg cal/m²/hr.

The excess air coefficient in the combustion chamber employing the system with a reliable liquid slag discharge fluctuated within the limits of $\alpha_{c.c}$ = 1.1 + 1.3.

The secondary air temperature varied between 300 to 325 C.

The mechanical failure of fuel particles to light, that is, to enter the combustion phase was established according to the fuel contents in the slag and ash collected in the ash catcher and in the ash carried off with the gas. It was shown earlier that unburned fuel particles appeared in the slag after the cup arrangement had been installed. The relation of the fuel content in the liquid slag to the grindability of the raw coal is shown in Fig. 5. This fuel content registered its minimum value when T_{75} = 40 per cent.

In general, however, the fuel content in the slag does not run high and measures from 2 to 4 per cent. The fuel content in the ash carry-off and in the ash collected by the ash collector totaled 4 to 10 per cent. By determining the fuel content, Q_4, in the slag the percentage of fuel loss from mechanical failure to enter combustion was found to not exceed 1 per cent. The dependence of the value of Q_4 on R_{75} (Fig. 6) shows that the least loss and hence the best value for mechanical failure to enter combustion occurs when the $R_{75} \approx 40\%$.

Fluctuations in the secondary air velocity from the slots of from 130 to 65 meters/sec had no practical effect upon the magnitude of the combustible loss in the slag.

The coefficient of ash removal in the slag varied from 0.7 to 0.9 while burning gaseous coal. The most reliable data was obtained in Test 4 which lasted the longest, 14 hr. The removal coefficient in this test along the six

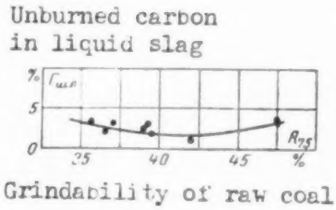


Fig. 5—The relationship of the fuel content of unburned carbon in the liquid slag on the grindability of raw coal

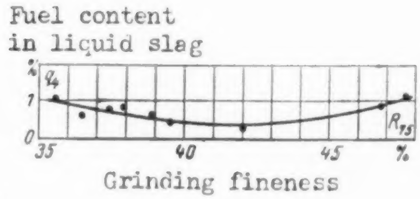


Fig. 6—The dependence of q_4 on the grinding fineness

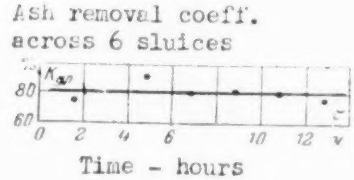


Fig. 7—The dependence of the slag catcher coefficient on the individual sluices during test 4

sluices was steady at about 80 per cent, Fig. 7. For the rest of the tests the ash removal coefficient of the slag did not drop basically below 80 per cent, Table I. All the tests in Table I were conducted with the combustion chamber operating along with the slag catcher. The content of the suspended particles in the gas stream leaving the slag catcher equaled 0.013 to 0.146 gr/kg. Of these gas-borne particles 1 to 3 per cent were more than 20 microns which is, according to available data, acceptable for gas turbine operation.

There was no chemical failure to light beyond the mixing chamber. A traverse of the gas analyses over the cross section of the chamber, Fig. 8, showed that at the middle inspection hole situated at the level of the secondary air slots the CO_2 content, Fig. 8a, gradually increases from the wall to the center and reaches 16 per cent. In the center the CO_2 value falls somewhat. The presence of CO was noticeable.

A similar traverse sampling of the gas at the level of inspection hole No. 5 recessed away from the secondary air slots showed, Fig. 8b, an almost uniform reading of CO_2 = 14 to 15 per cent. A small CO_2 content drop at the edges and in the center was observed and the CO content totaled up to 2 per cent here. In the lower inspection hole, 8c, the traverse of gas analyses in this test showed a nearly even percentage of CO_2 across the entire chamber diameter and attained values of 15 per cent and higher with only traces of CO observed. On the graph right, Fig. 8d, the gas analyses plotted were sampled from behind the mixing chamber and were taken across the diameter of the gas path. It can be seen from these samples that the chemical failure to light was totally non-existent.

The heat absorption of the chamber's walls is an important property. Its magnitude determines the air cooling design for the chamber. The chamber wall draws its heat mainly from the radiation of the jet flame. To guarantee admissible temperatures on the chamber walls and the fire-side ends of the rods an adequate heat transfer must be established on the air-cooled side of the rods. The specific heat absorption of the wall's surface is characterized by a large unevenness across individual sections resulting from the means of heat supply within the chamber. (An uneven thickness of the slagging layer, for instance, develops basically from the one sided periphery feeding of the secondary air, Fig. 2, through slots as well as from an uneven distribution of cooling tertiary air around the outside periphery of the combustion chamber.)

In the conducted tests a mean value for the specific heat absorption of the furnace surfaces cooled by air was obtained. Table II shows that this value fluctuated from 55 × 10³ to 100 × 10³ kg cal/m²/hr.

The effect of time upon the specific heat absorption was observed for Test 4 in Table II and has been plotted in Fig. 9. It shows but little variation and fluctuates around 100 × 10³ kg cal/m²/hr.

The increase in percentage of total heat absorbed by the furnace wall (14 to 16 per cent) in the tests shown in Table II is explained by the fact that the combustion chamber exit gas throat and cup outlet with its water cooling was added during the tests. This heat amounted to 4 to 5 per cent.

The manufacturing technique for heat transfer material used in the chamber did not work out satisfactorily because of the uneven temperature conditions at the furnace chamber exit as judged by the Boltzman criterion $\theta_0 = f(B_0)$. This comes about because the chamber operates in an area of a high value $\theta \geq 0.9$ where θ affects the B_0 criteria. As a result the heat transfer material was manufactured by a different method than usual wherein the specific heat absorption is considered to be a part of the absolute radiation of the ferric substance under an adiabatic temperature in the chamber.

$$\Delta = \frac{q \text{ air}}{q \text{ ferrous}} \qquad (1)$$

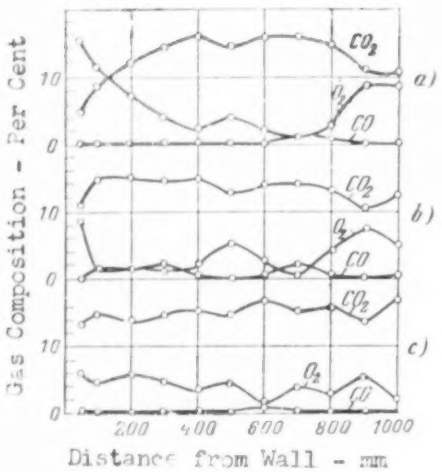
where q air = specific heat absorption of the furnace chamber wall, kg cal/m²/hr. and q ferrous = absolute radiation of the ferrous furnace chamber material under an adiabatic temperature in the chamber, kg cal/m²/hr. It can be written:

$$q \text{ air} = \sigma_0 T^4_{w} \epsilon/\psi \qquad (2)$$

$$q \text{ ferrous} = \sigma_0 T^4 \text{ adiabatic} \qquad (3)$$

TABLE II HEAT PERCEPTION OF THE COMBUSTION CHAMBER WALLS

Size →	1	2	3-4
Specific heat absorption of the surface cooled by air, q air = Q air/F_{air}, 10³ kg cal/m²/hr	71.5	76.0	
Total air transmitted by the fire wall, %, from the liquid heat: μ' = $Q_{wall\ heating}/Q_{fuel}$, %	14.3	15.7	
Unmeasured temperature $\theta_t = \dfrac{t_{gas}{}^{k.2} + 273}{t_{adiabatic}{}^{k.2} + 273}$	0.93	0.90	
Boltzman criteria for a ferrous chamber $B_0 = \dfrac{\theta_t}{F_{fire}} \times \dfrac{1}{q_{ferrous}} \times \dfrac{\mu}{1-\theta}$	0.550	0.468	
Relative radiation: Δ = q air/q ferrous	0.428	0.0365	
Temperature coefficient $\delta = \Delta/\psi$	0.223	0.19	



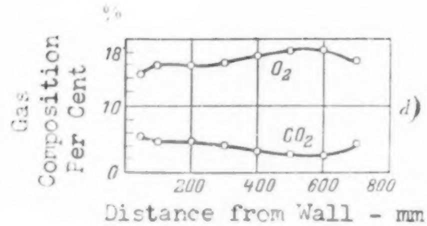


Fig. 8—Gas analysis traverse along chamber diameter

a—In the middle inspection hole No. 2. b—In the middle inspection hole No. 5. c—In the lower inspection hole No. 6. d—After the mixing chamber.

where

σ_0 = coefficient of the absolute radiation of the ferrous material

T_∞ = Effective temperature in the flame (jet), deg K

T adiabatic = Adiabatic temperature at the chamber exit (calculated) under actual excess air, deg K

ϵ_f = degree of blackness of the fuel radiation

ψ = coefficient of effective fire surface

then

$$\Delta = \frac{\sigma_0 T^4{}_\infty \epsilon_f \psi}{\sigma_0 T^4{}_{\text{adiabatic}}} = \frac{T^4{}_\infty}{T^4{}_{\text{adiabatic}}} \epsilon_f \psi \qquad (1)$$

designation $\beta = T^4{}_\infty / T^4$ adiabatic we have:

$$\Delta = \beta \epsilon_f \psi \qquad (5)$$

Here β describes the effective adiabatic temperature change and hence β depends on the excess air.

The degree of blackness ϵ_f for similar chambers can be assumed to be an equal unit. No sufficiently reliable data exists for the effective fire surface coefficient values ψ, especially for cyclone chambers. On the basis of test results on furnace chambers with liquid slag removal for boiler units the expression $\psi = 0.53 - 0.25\ t_3/1000$ is proposed where t_3 equals slag fusion temperature, deg C. From equation (5) $\beta = \Delta/\epsilon_f \psi$ the value $\beta = f(\alpha_K)$ is presented. Using this graph and knowing the value of ψ and ϵ_f we can determine Δ and after that the size of the specific heat absorption.

The secondary and tertiary air resistance of the chamber is an important characteristic of the combustion chamber influencing the efficiency of the gas turbine.

The secondary air resistance coefficient within the chamber referred to the dynamic air pressure in the slots discharge cross section proved to be equal to $\zeta_{dd} = 0.78$. The area of the slot opening totaled from 0.68 to 12.3 per cent of the chamber diametrical cross-section area.

The tertiary air resistance coefficient referred to the dynamic pressure of the tertiary air in the inter rod area proved to equal to $\zeta_{m.d.} = 51.5$.

The total secondary air resistance of the chamber totaled 800 mm of the water column and the tertiary air did not exceed 300 mm of the water column.

Conclusions

1. The chamber operated steadily with the liquid slag remover under excess air totaling up to 1.3 and $t_{air} = 350$ C.

2. Losses due to chemical failure to light, q_3, in all the tests were equal to zero. Losses due to mechanical failure to light, q_4, for Donets gaseous coal did not exceed 1 per cent. A relation between q_4 and the grindability was observed with the smallest when $R_{75} = 40$ per cent.

3. The slag catcher coefficient equalled ~ 80 per cent.

4. The heat absorption of the fire wall surface was distinguished by its significant unevenness along the periphery and the elevation of the chamber. The mean specific heat absorption of the fire wall surface cooled by air totaled 55×10^3 to 100×10^3 kg cal/m² hr.

5. The chamber resistance to the secondary air flow totaled ~ 800 mm of the water column. The resistance coefficient referred to the dynamic pressure of the secondary air in the slots discharge cross section was equal to 0.78. The air resistance of the chamber including the mixture chamber to tertiary air flow was within 140–300 mm of the water column.

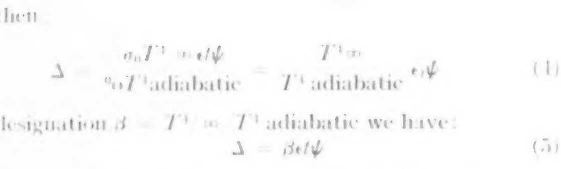


Fig. 9—Dependence of the specific heat absorption of the fire wall surface on the time in test 4

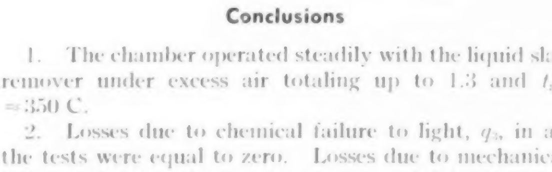


Fig. 10—The dependence of the effective adiabatic temperature coefficient on excess air

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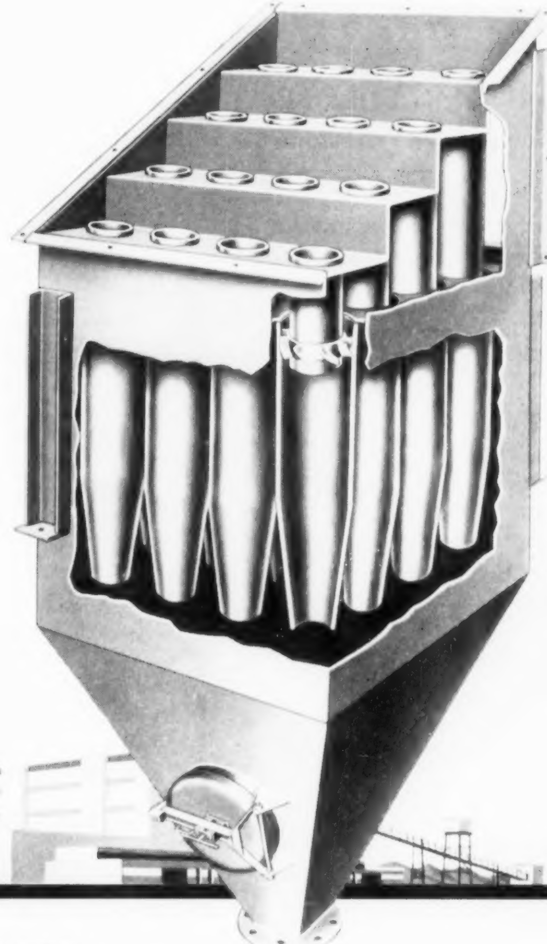

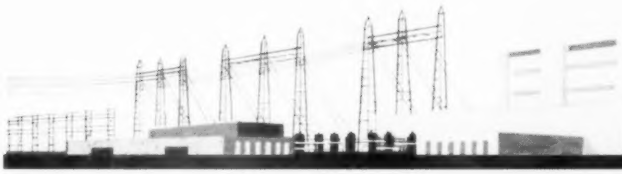

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REVIEW OF NEW BOOKS

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Introduction to Heat Transfer

By Aubrey I. Brown and Salvatore M. Marco

332 pages, $6.75

This volume is the third edition of a well-accepted textbook treatment of heat transfer. In it the coverage of the field has been enlarged to bring the material up to date and yet the authors' objective of a presentation understandable to third and fourth year engineering students has been achieved.

Principles of heat transfer are advanced and where possible supporting applications have been described to give the student a working knowledge of the principles in a variety of engineering problems. This technique, the authors believe, can give a good foundation for any advanced or more specialized studies the reader may elect to follow.

Symbols and notations have been revised in keeping with the general adoption of American Standards. Two new chapters appear: a chapter on Fluid Flow in the Convection Process and one on Graphical and Numerical Methods for Heat Conduction Problems. In addition the authors have included a new section on Design of Electrical Transformers plus new material on Fundamental Units to combat difficulties students experience from confusion of force and mass units.

Introduction to Nuclear Engineering

By Richard Stephenson

491 pages, $9.50

Specifically designed for a one-year senior or graduate course is nuclear engineering this text could serve equally well as a reference book for practicing engineers. It is a completely revised version of an earlier edition of this same title and was so revised to include information released at the Geneva Conference.

Those topics unique to the nuclear field have been given preference in emphasis over those topics akin to standard engineering practice. As a result the engineer with a good foundation in the standard curriculum can gain a basic understanding of the problems peculiar to the nuclear field and at the same time obtain an introduction which will permit later specialization.

The teaching aids, problems and exercises the author tested out in his first edition appear here but are altered to pass along the experience of the first book. The general interest areas of nuclear fission, the nuclear chain reactor, reaction theory, radiation shielding, reactor materials, reactor control, separation of stable isotopes, chemical processing of radioactive materials and remote handling are covered.

High Temperature Water Systems

By Owen S. Lieberg

224 pages, $6.50

The author, a leading consultant in this field, responsible for design of some of the largest HTW systems now operating in the United States, Canada and Great Britain, has worked into this book much original design data used successfully in actual systems. Tables, graphs

photographs and specifications serve as a working guide.

Particularly stressed are points which are critical in HTW design: theory and practice of pressurization; selection of pumps, boilers and valves; piping and controls. An entire boiler and auxiliary specification for HTW is included in the Appendix. Two chapters are devoted to space and process heating, with applications of HTW-fed unit heaters, central fan systems, water-to-water heat exchangers and convertors for space heating, domestic hot-water and low-pressure process steam. An extensive discussion of specific military and naval installations, is given.

Fine Particle Measurement

By Clyde Orr, Jr. and J. M. Dalla Valle

353 pages, 5 1/2 × 8 1/4 in., $10.50

The entire field of fine-particle application, research, test and measurement has grown so rapidly since one of the above authors, J. M. Dalla Valle, presented his earlier work on *Micromeritics* that the single sector of fine particle measurement merits a reference text to expedite further advances. Here, for the first time in a single volume, is a detailed discussion of the important techniques currently used in the research laboratories for the measurement of particle size, surface and pore volume. Something like seventy techniques are described. Of equal value is an up-to-date bibliography of about 400 references held to be of immediate aid to those in chemical, engineering and physics fields.

The Metallurgical, Chemical and Other Process Uses of Coal

By R. A. Glenn and H. J. Rose

64 pages, 8 1/2 × 11 in., $3

The versatility, present importance and future potentials of coal as an industrial raw material make up the subject matter of this book. All the processes covered are ones now in commercial use or at the demonstration plant stage. None of those now under study in research laboratories are included. Further, the bituminous coal and its products coke and synthesis gas with some minor coal products represent the area of the book's interest. Coal carbonization and its products, coal tar, light oil and ammonia, are not included.

The information offered consists in the main of nine large tables which show for each process (*a*) the typical yields or unit requirements of fuel and power (*b*) the typical end products and their uses (*c*) the present and estimated future tonnage requirements of coal and coke with the sources of information cited.

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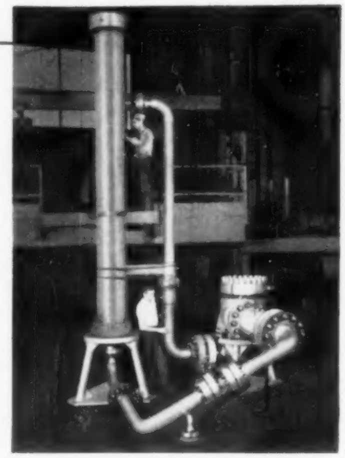

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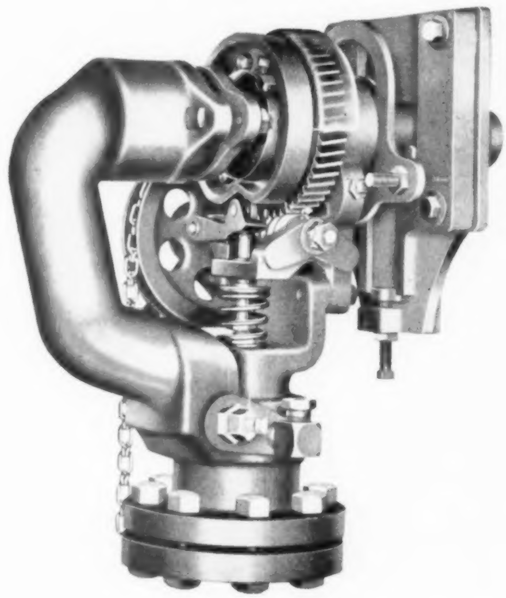

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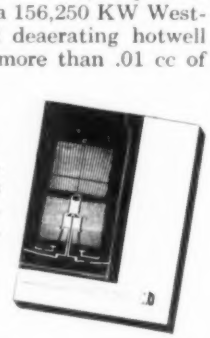

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CONSUMERS POWER CO. (3 Plants) DALLAS POWER & LIGHT CO. (3 Plants)
DUKE POWER CO. (6 Plants) • FLORIDA POWER & LIGHT CO. (5 Plants)
GEORGIA POWER CO. (3 Plants) • HOUSTON LIGHTING & POWER CO. (4 Pl
ILLINOIS POWER CO. (2 Plants) • INDIANAPOLIS POWER & LIGHT CO. (2
IOWA POWER & LIGHT CO. (2 Pla KANSAS POWER & LIGHT CO. (4 Plants)
LONG ISLAND LIGHTING CO. (3 Pl LOUISVILLE GAS & ELECTRIC CO. (2 Plant
MINNESOTA POWER & LIGHT CO. (3 MISSISSIPPI POWER & LIGHT CO. (2 Plant
MONTAUP ELECTRIC CO. (2 Plants) EW YORK STATE ELECTRIC & GAS CO. (2
NIAGARA MOHAWK POWER (4 Pl • OHIO EDISON CO. (4 Plants) •
OHIO POWER CO. (4 Plants) • OKLAHOMA GAS & ELECTRIC CO. (2 Pla
PACIFIC GAS & ELECTRIC CO. (2 Pl P ELPHIA ELECTRIC CO. (5 Plants)
POTOMAC ELECTRIC POWER CO. (5 ERVICE ELECTRIC & GAS CO. (5 Pl
PUBLIC SERVICE CO. of INDIANA (4 Plants) PUBLIC SERVICE CO. of OKLAHO
CITY PUBLIC SERVICE BOARD (SAN ANTONIO) (3 Plants) • SAN DIEGO GAS & ELECTRIC CO. (2
SO. CAROLINA ELECTRIC & GA O. CALIF. EDISON CO. (6 Plan
SOUTHWESTERN PUBLIC SERVIC NNESSEE VALLEY AUTHORITY
TEXAS ELECTRIC SERVICE CO. (3 EXAS POWER & LIGHT CO. (3
TOLEDO EDISON CO. (2 Plants UNITED ILLUMINATING CO.
UTAH POWER & LIGHT CO. (2 Plants) • VIRGINIA ELECTRIC & POWER CO. (4 Plants)

Model MP-3000 shown is for both new and old boilers having pressures to 3000 psig. Also available in Model MP-900 for boiler pressures to 900 psig.

8266

Undoubtedly the best recommendation for the Diamond "Multi-Port" Gauge is the public utilities that use it and have placed repeat orders to equip additional boilers. A few of these are mentioned here with a note of the number of plants equipped. For the many advantages of the "Multi-Port", ask your local Diamond office or write directly to Lancaster for Bulletin 1174 (Model MP-3000) or Bulletin 2044 (Model MP-900).

Diamond

DIAMOND POWER SPECIALTY CORP.
LANCASTER, OHIO
Diamond Specialty Limited • Windsor, Ontario


NEW IDEAS IN CHEMICAL CLEANING